ENGINEERING AND GINNING

Second-Stage Mote 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, the Environmental Protection Agencey (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 second-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 had second-stage mote systems where the exhaust airstreams were not combined with first- stage mote systems. In terms of capacity, the five gins were typical of the industry, averaging 30.0 bales/h during testing. Some test runs were excluded from the test averages because they failed to meet EPA Method 201A Test criteria. Also, during other test runs, included in the analyses, cotton lint fibers were 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 second-stage mote system PM$_{2.5}$ emission factor based on the five tests (11 total test runs) was 0.0025 kg/227-kg bale (0.0055 lb/500-lb bale). The second-stage mote system average emission factors for PM$_{10}$ and total particulate were 0.010 kg/bale (0.022 lb/bale) and 0.013 kg/bale (0.029 lb/bale), respectively. The second-stage mote system PM$_{2.5}$ emission rate from test averages ranged from 0.038 to 0.13 kg/h (0.084-0.28 lb/h). System average PM$_{10}$ and total particulate emission factors were lower than those currently published in EPA AP-42. The ratios of second-stage mote system PM$_{2.5}$ to total particulate, PM$_{2.5}$ to PM$_{10}$, and PM$_{10}$ to total particulate were 19.1, 25.0, and 76.6%, 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-mm (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, 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 second-stage mote systems.

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There are published PM$_{10}$ (particulate matter with a particle diameter less than or equal to a nominal 10-mm aerodynamic equivalent diameter) and total particulate emission factors for cotton gins 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 PM$_{10}$ 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 PM$_{10}$ 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 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 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, but has steadily declined 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 about 25 bales per hour across the belt (Valco et al., 2003, 2006, 2009, 2012).
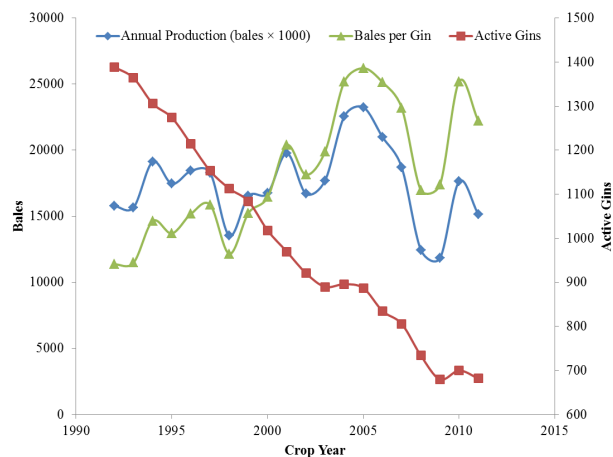
Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

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-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 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.

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 mote systems that operate independently with separate fans and cyclones, denoted as first-stage mote systems, or second-stage mote systems. The material handled by the mote cyclones typically includes small trash and particulate, and large amounts of lint fibers (Fig. 4).

Figure 4. Photograph of typical trash captured by the 2nd stage mote system cyclones.
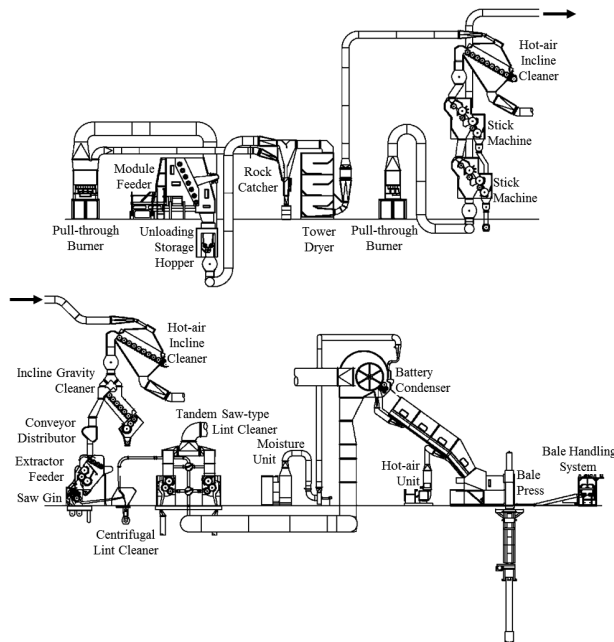

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).
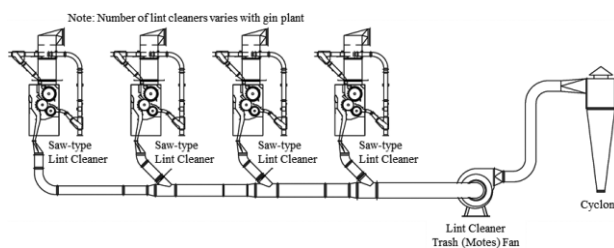

Figure 3. Typical cotton gin 2nd stage mote system layout (Courtesy Lummus Corporation, Savannah, GA).

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 may 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).
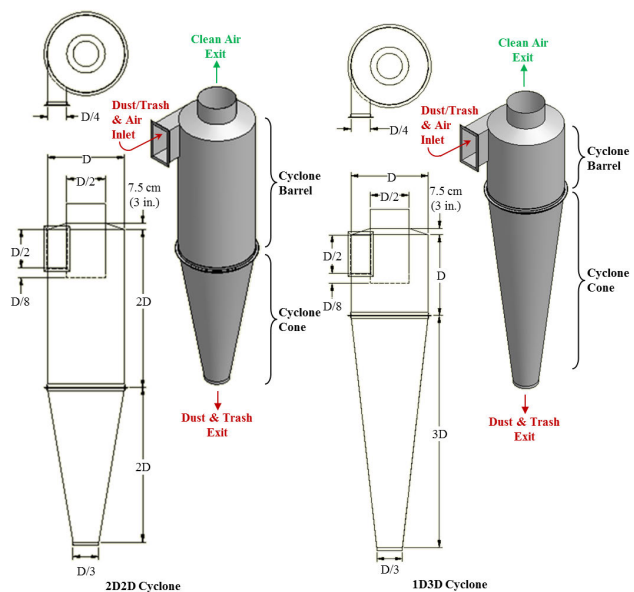

Figure 5. 2D2D and 1D3D cyclone schematics.

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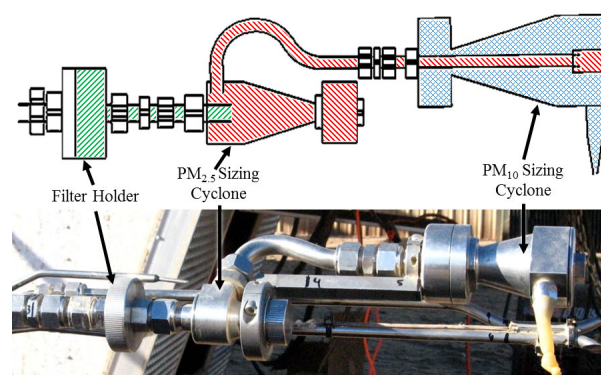
METHODS

Two advisory groups were established for this project. An industry group consisting 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 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 second-stage mote 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 (CFR, 2010) 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 10-2.5 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 PM$_{10}$ 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 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 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.
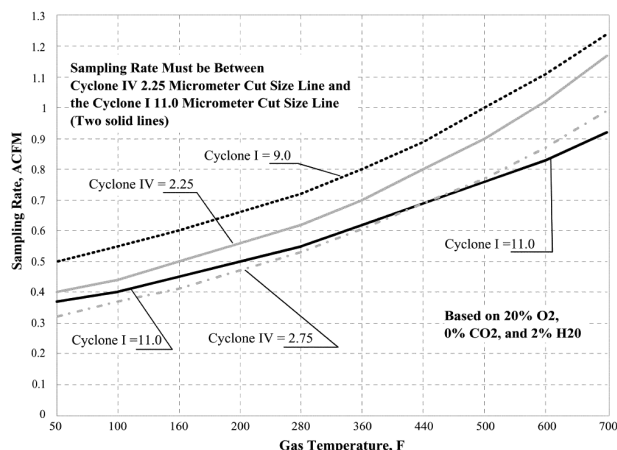
Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = PM$_{10}$ sizing cyclone and Cyclone IV = PM$_{2.5}$ sizing cyclone (Gas temperatures for the 2nd stage mote systems tested ranged from 16 to 45°C [61-113°F]).

Only one stack from each second-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 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 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 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 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).

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber (21 ± 2°C; 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 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 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.
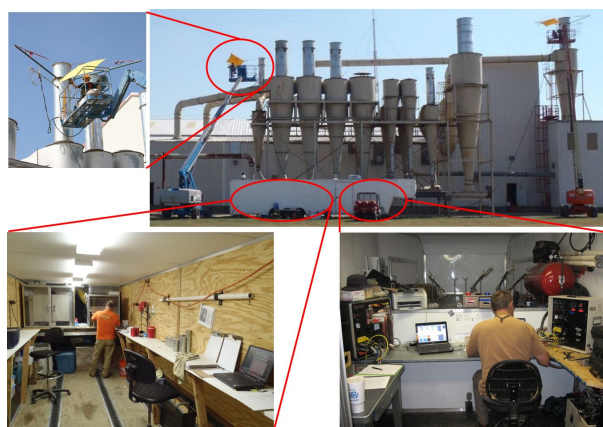

Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

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 second-stage mote systems. The second-stage mote systems sampled were typical for the industry, but varied among the gins. After the first-stage lint cleaning systems, the lint was cleaned a second time in three second-stage lint cleaning systems at gin A. The trash removed from the lint in the second-stage lint cleaning systems was combined in the second-stage mote system and pneumatically conveyed from the

lint cleaners through a fan and exhausted through one or more cyclones (Fig. 10). The second-stage mote system at gin C was essentially the same, except the second-stage mote system pulled trash from two second-stage lint cleaning systems (Fig. 11). At gin B, the second-stage mote system was similar to that at gin C, but each second-stage lint cleaning system processed lint from double first-stage lint cleaning systems (Fig. 12). The second-stage mote systems at gins D and F were also similar, but the systems at those gins pulled material from four second-stage lint cleaning systems (Fig. 13).
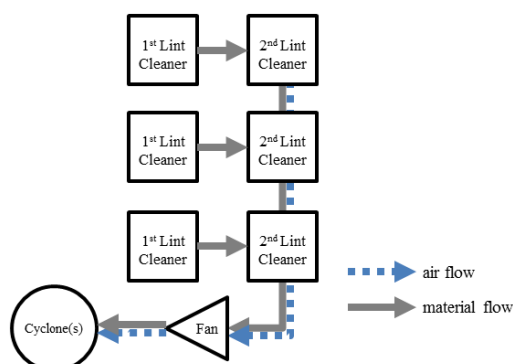
Figure 10. Schematic of 2nd stage mote system pulling material from three 2nd stage lint cleaning systems (gin A).
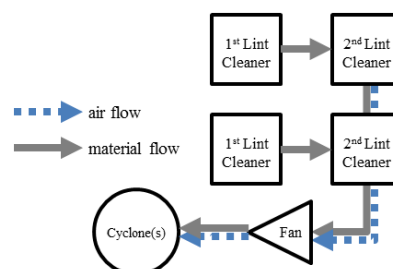
Figure 11. Schematic of 2nd stage mote system pulling material from two 2nd stage lint cleaning systems (gin C).
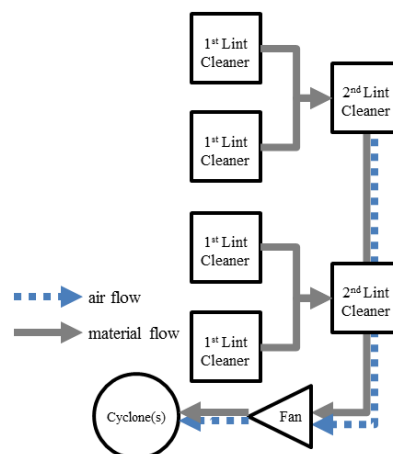
Figure 12. Schematic of 2nd stage mote system pulling material from two 2nd stage lint cleaning systems each preceded by double 1st stage lint cleaning systems (gin B).
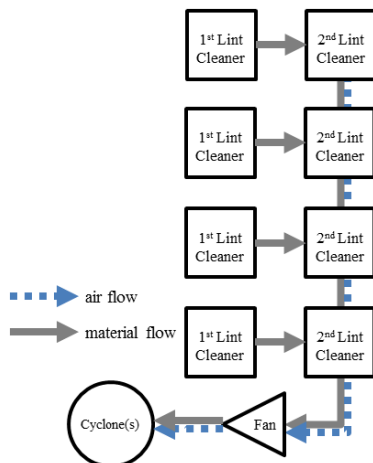
Figure 13. Schematic of 2nd stage mote system pulling material from four 2nd stage lint cleaning systems (gins D and F).

Figure 14. 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.

All second-stage mote systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among the gins (Table 1 and Fig. 14). All the gins, except gin B, 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 gin B was exhausted through a single cyclone. Inlets on all the second-stage mote cyclones were 2D2D type, except gin A that had inverted 1D3D inlets. Standard cones were present on second-stage mote cyclones at all gins, except gins B and C that had expansion chambers. The cyclones tested at gins A, B, D, and F had mote cyclone robber systems pulling airflow from their 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).

RESULTS

Table 2 shows the test parameters for each Method 201A test run for the second-stage mote systems sampled at the five gins. The system average ginning rate was 30.0 bales/h and test average ginning rates at each gin ranged from 16.7 to 45.7 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).

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 ($100 \pm 20\%$) for valid PM$_{2.5}$ and PM$_{10}$ 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 gin A, in the second and third test runs for gin C, or the first and second test runs for gin D; 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 were not met in the third test run for gin A, the second and third test runs for gin D, or the first test run for gin F, 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 the second test run for gin A, the first test run for gin C, the first and second test runs for gin D, or the first and third test runs for gin F, thus the data associated with these runs were omitted from the PM$_{10}$ test averages.

Sampling rates ranged from 9.9 to 12.9 standard l/min (0.350-0.455 standard ft^3/min) (Table 2). The stack gas temperatures ranged from 16 to 45°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 PM$_{10}$ cut size criteria as secondary.

Table 1. Abatement device configuration[z] for second-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	2	dual	standard	robber
B	1D3D	2D2D	1	1	single	expansion chamber	robber
C	1D3D	2D2D	1	2	dual	expansion chamber	hopper
D	1D3D	2D2D	1	2	dual	standard	robber
F	1D3D	2D2D	1	2	dual	standard	robber

[z] **Figures 5 and 14**

[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**

Table 2. Cotton gin production data and stack sampling performance metrics for the second-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	21.8	15.3	3016	100	2.44	10.9	11.3	0.399	16	61
	2	23.6	15.6	3068	94	2.62	11.4[w]	10.7	0.379	19	65
	3	23.0	15.1	2982	116[x]	2.14[w]	10.1	12.9	0.455	22	72
Test Average		22.8	15.4	3022							
B	1	28.3	16.2	3186	100	2.33	10.7	11.9	0.420	39	103
	2	28.4	16.3	3200	99	2.36	10.8	11.8	0.417	39	103
	3	30.5	16.3	3199	100	2.32	10.7	12.0	0.423	40	104
Test Average		29.1	16.2	3195							
C	1	17.3	14.6	2874	100	2.48	11.2[w]	10.8	0.381	26	78
	2	17.3	14.3	2816	114[x]	2.32	10.8	11.4	0.404	27	80
	3	15.5	14.3	2815	111[x]	2.25	10.6	11.7	0.414	27	80
Test Average		16.7	14.4	2835							
D	1	35.5	15.5	3057	87[x]	2.62	11.6[w]	10.4	0.367	29	85
	2	35.0	15.2	3000	84[x]	2.80[w]	12.1[w]	9.9	0.350	31	88
	3	36.8	15.7	3082	99	2.22[x]	10.5	12.0	0.425	32	89
Test Average		35.8	15.5	3046							
F	1	46.8	14.4	2838	99	2.76[w]	11.7[w]	11.1	0.392	45	113
	2	44.5	14.4	2837	108	2.46	10.9	12.1	0.427	43	110
	3	45.7	14.9	2929	99	2.63	11.4[w]	11.4	0.402	41	107
Test Average		45.7	14.6	2868							
System Average		30.0	15.2	2993							

[z] **227 kg (500 lb) equivalent bales**

[y] **slpm = standard l/m, 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 PM$_{10}$ (10.0 ± 1.0 µm) aerodynamic cut size criteria**

PM$_{2.5}$ emissions data (ginning and emission rates and corresponding emission factors) for the second-stage mote systems are shown in Table 3. The system average PM$_{2.5}$ emission factor was 0.0025 kg/bale (0.0055 lb/bale). The test average emission factors at each gin ranged from 0.0013 to 0.0035 kg (0.0029 to 0.0078 lb) per bale and PM$_{2.5}$ emission rates ranged from 0.038 to 0.13 kg/h (0.084-0.28 lb/h). PM$_{10}$ emissions data (ginning and emission

rates and corresponding emission factors) for the second-stage mote systems are shown in Table 4. The system average PM$_{10}$ emission factor was 0.010 kg/bale (0.022 lb/bale). The test average emission factors ranged from 0.0049 to 0.017 kg (0.011 to 0.038 lb) per bale and emission rates ranged from 0.15 to 0.63 kg/h (0.34-1.40 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the second-stage mote systems

are shown in Table 5. The system average total particulate emission factor was 0.013 kg/bale (0.029 lb/bale). The test average emission factors ranged from 0.0064 to 0.021 kg (0.014-0.047 lb) per bale. Test average total particulate emission rates ranged from 0.21 to 0.79 kg/h (0.46-1.74 lb/h). The ratios of $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 19.1, 25.0, and 76.6%, respectively (ratios calculated using tables 3, 4, and 5 may vary slightly from those listed due to rounding).

The second-stage mote system total particulate emission factor average for this project was about 10.3% of the EPA AP-42 published value for the mote fan (EPA, 1996a, 1996b), which is an equivalent system to combined first and second-stage mote systems. The range of test average total particulate emission factors determined for this project was lower than the range of AP-42 emission factor data. The second-stage mote system PM_{10} emission factor average for this project was 16.9% of the EPA AP-42 published value for the mote fan. The test average PM_{10} emission factor range was also lower than the AP-42 emission factor data range.

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

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.11	0.25	0.0053	0.012
	2	0.038	0.083	0.0016	0.0035
	3[y]	0.032	0.071	0.0014	0.0031
Test Average (n=2)		0.076	0.17	0.0034	0.0075
B	1	0.029	0.064	0.0010	0.0023
	2	0.041	0.091	0.0015	0.0032
	3	0.044	0.10	0.0014	0.0032
Test Average (n=3)		0.038	0.084	0.0013	0.0029
C	1	0.046	0.10	0.0027	0.0059
	2	0.029	0.065	0.0017	0.0038
	3	0.044	0.10	0.0029	0.0063
Test Average (n=3)		0.040	0.088	0.0024	0.0053
D	1	0.13	0.28	0.0035	0.0078
	2[y]	0.13	0.29	0.0038	0.0083
	3[y]	0.15	0.32	0.0039	0.0087
Test Average (n=1)		0.13	0.28	0.0035	0.0078
F	1[y]	0.10	0.23	0.0022	0.0048
	2	0.087	0.19	0.0019	0.0043
	3	0.070	0.16	0.0015	0.0034
Test Average (n=2)		0.079	0.17	0.0017	0.0038
System Average (n=5)				0.0025	0.0055

[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. PM_{10} emissions data for the second-stage mote systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.18	0.40	0.0084	0.018
	2[y]	0.18	0.39	0.0075	0.017
	3	0.12	0.27	0.0054	0.012
Test Average (n=2)		0.15	0.34	0.0069	0.015
B	1	0.33	0.72	0.012	0.026
	2	0.30	0.65	0.010	0.023
	3	0.27	0.59	0.0088	0.019
Test Average (n=3)		0.30	0.66	0.010	0.023
C	1[y]	0.19	0.42	0.011	0.024
	2	0.18	0.41	0.011	0.024
	3	0.16	0.36	0.010	0.023
Test Average (n=2)		0.17	0.38	0.011	0.023
D	1[y]	0.96	2.11	0.027	0.059
	2[y]	0.93	2.06	0.027	0.059
	3	0.63	1.40	0.017	0.038
Test Average (n=1)		0.63	1.40	0.017	0.038
F	1[y]	0.25	0.55	0.0053	0.012
	2	0.22	0.48	0.0049	0.011
	3[y]	0.22	0.49	0.0049	0.011
Test Average (n=1)		0.22	0.48	0.0049	0.011
System Average (n=5)				0.010	0.022

[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 second-stage mote systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.20	0.45	0.0094	0.021
	2	0.21	0.46	0.0089	0.020
	3[y]	0.15	0.32	0.0063	0.014
Test Average (n=2)		0.21	0.46	0.0092	0.020
B	1	0.39	0.85	0.014	0.030
	2	0.36	0.80	0.013	0.028
	3	0.31	0.69	0.010	0.023
Test Average (n=3)		0.35	0.78	0.012	0.027
C	1	0.27	0.60	0.016	0.035
	2[y]	0.25	0.54	0.014	0.031
	3[y]	0.33	0.73	0.021	0.047
Test Average (n=1)		0.27	0.60	0.016	0.035
D	1[y]	1.14	2.51	0.032	0.071
	2[y]	1.14	2.52	0.033	0.072
	3	0.79	1.74	0.021	0.047
Test Average (n=1)		0.79	1.74	0.021	0.047
F	1	0.31	0.68	0.0066	0.014
	2	0.31	0.68	0.0069	0.015
	3	0.26	0.57	0.0057	0.013
Test Average (n=3)		0.29	0.64	0.0064	0.014
System Average (n=5)				0.013	0.029

[z] 227 kg (500 lb) equivalent bales

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

Figure 15 shows an example of samples recovered from a typical second-stage mote 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, in the atypical sample shown in Figure 16, lint fibers passed through the PM$_{10}$ 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 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.
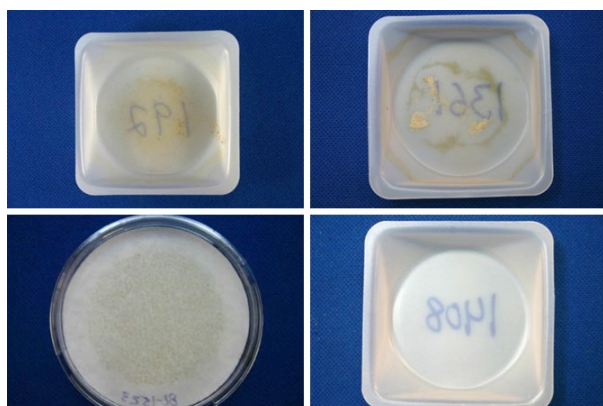
Figure 15. Typical EPA Method 201A filter and sampler head acetone washes from the 2nd stage mote system. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

Figure 16. Atypical EPA Method 201A filter and sampler head acetone washes from the 2nd stage mote system with lint in all three washes and on the filter. 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 Method 201A to fill the data gap that exists for PM$_{2.5}$ cotton gin emissions data. Five of the seven gins had second-stage mote systems where the exhaust airstreams were not combined with first-stage mote systems. 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 30.0 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 second-stage mote system PM$_{2.5}$ emission factor based on the five gins tested (11 total test runs) was 0.0025 kg/227-kg bale (0.0055 lb/500-lb bale). The second-stage mote system emission factors for PM$_{10}$ and total particulate were 0.010 kg/bale (0.022 lb/bale) and 0.013 kg/bale (0.029 lb/bale), respectively. The gin test average PM$_{2.5}$, PM$_{10}$ and total particulate emission rates ranged from 0.038 to 0.13 kg/h (0.084-0.28 lb/h), 0.15 to 0.63 kg/h (0.34-1.40 lb/h) and 0.21 to 0.79 kg/h (0.46-1.74 lb/h), respectively. System average PM$_{10}$ and total particulate emission factors were lower than those currently published in EPA AP-42. The ratios of second-stage mote system PM$_{2.5}$ to total particulate, PM$_{2.5}$ to PM$_{10}$, and PM$_{10}$ to total particulate were 19.1, 25.0, and 76.6%, respectively. These data are the first published data to document PM$_{2.5}$ emissions from second-stage mote systems at cotton gins.

DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the Oklahoma State University or U.S. Department of Agriculture. Oklahoma State University and USDA are equal opportunity providers and employers.

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