

## ENGINEERING AND GINNING

### Mote Cyclone Robber System PM<sub>10</sub> Emission Factors and Rates for Cotton Gins: Method 201A PM<sub>10</sub> 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. The impetus behind this project was the urgent need to collect cotton gin emissions data to address current regulatory issues. A key component of this study was focused on EPA emission factors for particulate matter with a particle diameter nominally less than or equal to 10  $\mu\text{m}$  (PM<sub>10</sub>). The 1996 EPA AP-42 emission factors were assigned quality ratings, from A (Excellent) to E (Poor), to assess the quality of the data being referenced. Emission factor quality ratings for cotton gins were extremely low. Also, some commonly used cotton gin systems were not represented or were combined with another system under a single emission factor in AP-42. There were no 1996 EPA AP-42 emission factors published for mote cyclone robber systems. The objective of this study was to collect PM<sub>10</sub> emission factor data for mote cyclone robber systems at cotton gins located in regions across the cotton belt based on 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, 2) production capacity, 3) processing systems, and 4) abatement technologies. Three of the seven gins had mote cyclone robber systems. In terms of capacity, the three gins were typical of the industry, averaging 28.0 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  $\leq 10 \mu\text{m}$  samples. This larger lint material can affect the reported emissions data, but EPA Method 201A does not suggest methods to account for these anomalies. The mote cyclone robber system average emission factors for PM<sub>10</sub> and total particulate were 0.028 kg/227-kg bale (0.061 lb/500-lb bale) and 0.039 kg/bale (0.087 lb/bale), respectively. The mote cyclone robber system PM<sub>10</sub> emission rate test averages ranged from 0.36 to 1.71 kg/h (0.79-3.77 lb/h). The ratio of mote cyclone robber system PM<sub>10</sub> to total particulate was 70.5%.**

U.S. Environmental Protection Agency (EPA) emission factors were published in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996b). These factors were assigned a rating from A (Excellent) to E (Poor) that is used to assess the quality of the data being referenced. In the 1996 EPA AP-42, there are emission factors for particulate matter with a particle diameter less than or equal to a nominal 10- $\mu\text{m}$  (PM<sub>10</sub>) aerodynamic equivalent diameter listed for 11 common cotton gin systems. The EPA emission factor quality ratings for these data are extremely low. Cotton gin data received these low ratings because they were collected almost exclusively from a single geographical region (EPA, 1996a). The AP-42 data are limited in that some systems commonly used in cotton gins are not represented or are combined with another system under a single emission factor (e.g., 1<sup>st</sup> and 2<sup>nd</sup> stage lint-cleaning systems are represented by lint cleaners). Cotton ginners' associations across the cotton belt, including the National, Texas, Southern, Southeastern, and California associations, agreed that there was an urgent need to collect additional cotton gin emissions data to address current regulatory issues. Working with 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

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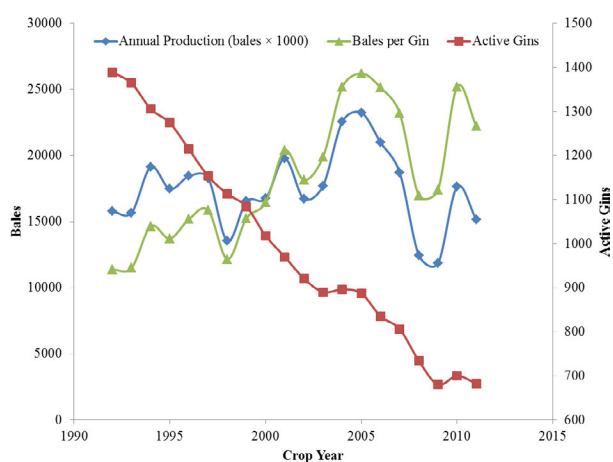
is part of a series that details cotton gin emissions measured by stack sampling. Each manuscript in the series addresses a specific cotton ginning system. The systems covered in the series include: unloading, 1<sup>st</sup> stage seed-cotton cleaning, 2<sup>nd</sup> stage seed-cotton cleaning, 3<sup>rd</sup> stage seed-cotton cleaning, overflow, 1<sup>st</sup> stage lint cleaning, 2<sup>nd</sup> stage lint cleaning, combined lint cleaning, cyclone robber, 1<sup>st</sup> stage mote, 2<sup>nd</sup> stage mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser, and master trash. This report focuses on PM<sub>10</sub> emissions from mote robber systems.

There were no 1996 EPA AP-42 average emission factors for mote cyclone robber systems (EPA, 1996b). The two systems listed in AP-42 that were similar to mote cyclone robber systems were the cyclone robber and mote fan. The AP-42 PM<sub>10</sub> emission factor for the cyclone robber was 0.024 kg (0.052 lb) per 217-kg [480-lb] and was based on one test (EPA, 1996a, b). The AP-42 PM<sub>10</sub> average emission factor for the mote fan was 0.060 kg (0.13 lb) per bale with a range of 0.023 to 0.14 kg (0.050-0.30 lb) per bale. This average and range was based on six tests conducted in one geographical location. The AP-42 total particulate emission factor for the cyclone robber was 0.083 kg (0.18 lb) per bale and was based on one test. 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. This average and range was based on nine tests conducted in one geographical location. The EPA emission factor quality ratings for the cyclone robber and mote fan PM<sub>10</sub> and total particulate factors were D, which is the second lowest possible rating (EPA, 1996a). Based on the system design, it would be expected that the mote cyclone robber would have lower emission factors than the mote fan and higher emission factors than the cyclone robber.

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 cot-

ton 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.

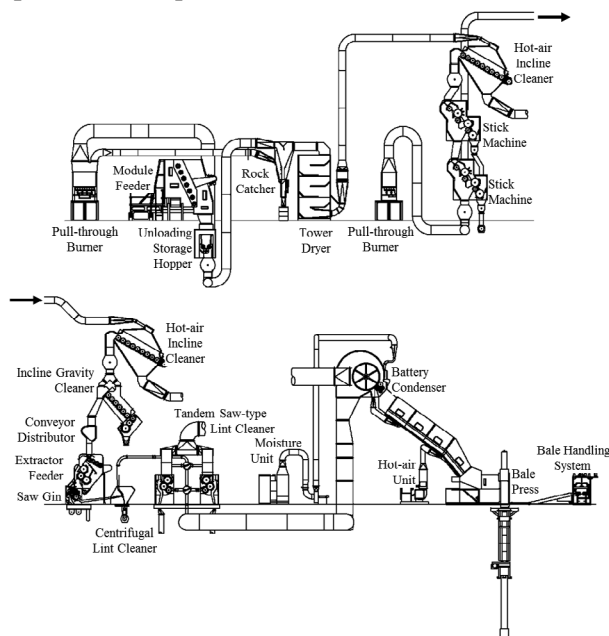
Cotton ginning is a seasonal industry with the ginning season lasting from 75 to 120 days, depending on the size and condition of the crop. Although the trend for U.S. cotton production remained generally flat at about 17 million bales per year during the last 20 years, production from one year to the 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 fewer than 700 in 2011. Consequently, the average volume of cotton handled by each gin has risen and gin capacity has increased to an average of approximately 25 bales per hour across the U.S. cotton belt (Valco et al., 2003, 2006, 2009, 2012).



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

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 assist with drying the seed cotton and remove foreign matter prior to ginning. Ginning systems also remove

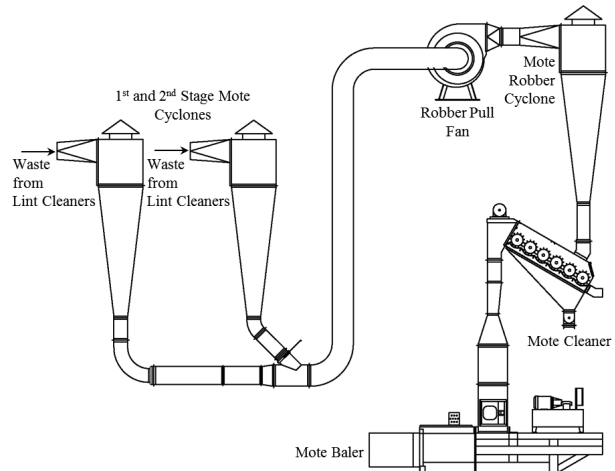
foreign matter and separate the cotton fiber from seed. Lint-cleaning systems further clean the cotton lint after ginning. The battery condenser and packaging systems combine lint from the lint-cleaning systems and compress the lint into dense bales for efficient transport. Cotton gin systems produce 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.



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

Mote cyclone robber systems are typically used to remove material captured by the mote system cyclones (waste streams from the lint-cleaning systems) (Fig. 3) and also might remove material from cyclones controlling emissions from lint conveying systems (lint cleaning and battery condenser). Material captured by these cyclones must be handled and conveyed from the trash exit of the cyclone or the materials would buildup and eventually choke or block the airflow in the cyclone, reducing or stopping its cleaning ability. In the case of cyclones that handle airstreams laden with higher amounts of lint (mote system cyclones), it might not be practical to convey the high-lint-content material mechanically, because lint tends to “rope-up” and collect on the moving

parts. Also, this high-lint-content material, referred to as “motes”, has considerable value, especially when cleaned. Thus this material is pulled by suction from the trash exit of the cyclones and pneumatically conveyed via a mote cyclone robber system to another cyclone that drops the motes directly into a machine for cleaning. The material handled by the mote cyclone robber cyclones typically includes small trash and particulate and large amounts of lint fibers (Fig. 4).



**Figure 3. Typical cotton gin mote cyclone robber system layout (Courtesy Lummus Corporation, Savannah, GA).**



**Figure 4. Photograph of typical trash captured by the mote cyclone robber 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  $15.2 \pm 2$

m/s ( $3000 \pm 400$  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  $16.3 \pm 2$  m/s ( $3200 \pm 400$  fpm).

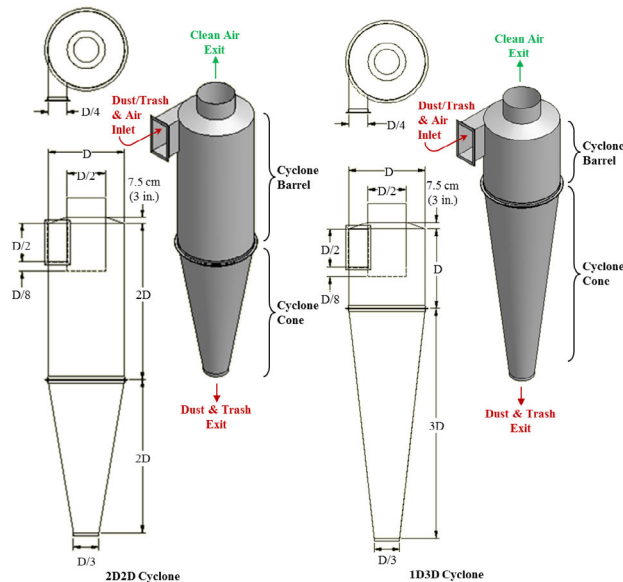


Figure 5. 2D2D and 1D3D cyclone schematics.

The objective of this study was to collect PM<sub>10</sub> emission factor data for mote cyclone robber systems with cyclones for emissions control at cotton gins located in regions across the cotton belt based on EPA-approved stack sampling methodologies.

## METHODS

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

Seven cotton gins were sampled across the cotton belt. Key factors for selecting specific cotton gins included: 1) facility location, 2) production capacity, 3) processing systems, and 4) abatement technologies. Operating permits, site plans, and aerial photographs were reviewed to evaluate potential sites. On-site visits were conducted on all candidate gins to evaluate the process systems and gather information including system condition, layout, capacities, and standard operation. Using

this information, several gins from each selected geographical region were selected and prioritized based on industry advisory group discussions. Final gin selection from the prioritized list was influenced by crop limitations and adverse weather events in the region.

Based on air quality advisory group consensus, EPA Method 201A was used to sample the mote cyclone robber system at each gin. Method 201A was revised in 2010 to incorporate options for PM<sub>2.5</sub> (particulate matter with particle diameter less than or equal to a nominal 2.5- $\mu\text{m}$  aerodynamic equivalent diameter) sampling (CFR, 2010); these revisions did not affect the PM<sub>10</sub> stack sampling methodology used in this project. Method 201A is a constant sampling-rate procedure. For the PM<sub>10</sub> sampling methodology, 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<sub>10</sub> 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 cyclone are described in detail in Method 201A (CFR, 2010). The mass of each size fraction was determined by gravimetric analysis and included:  $> 10 \mu\text{m}$  (PM<sub>10</sub> sizing cyclone catch acetone wash) and  $\leq 10 \mu\text{m}$  (PM<sub>10</sub> sizing cyclone exit acetone wash and filter). The PM<sub>10</sub> mass was determined by adding the mass of particulates captured on the filter and the  $\leq 10 \mu\text{m}$  wash. Total particulate was determined by adding the PM<sub>10</sub> mass and the mass of the  $> 10 \mu\text{m}$  wash.

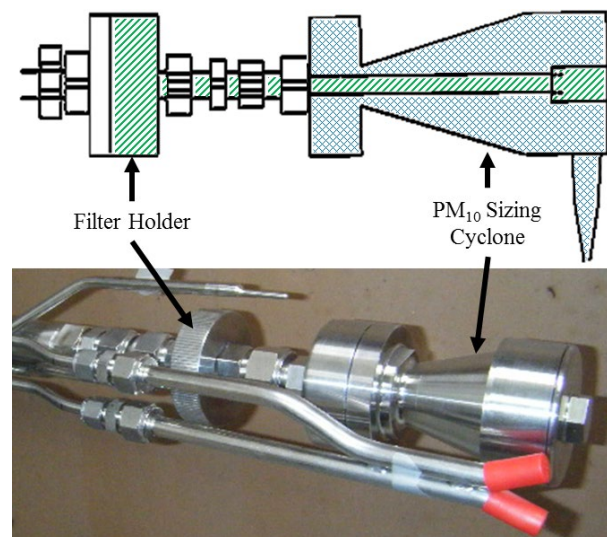
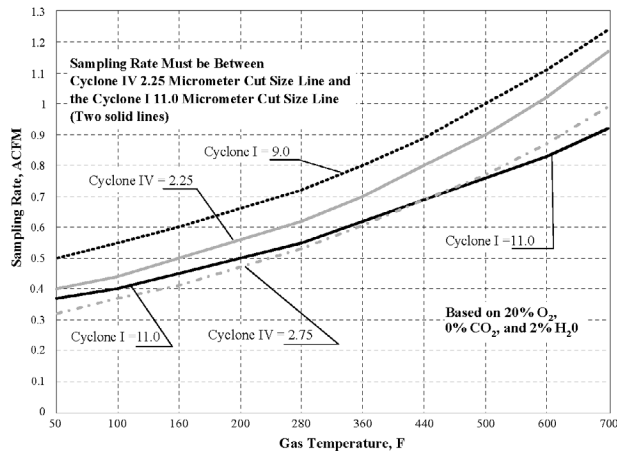


Figure 6. EPA Method 201A PM<sub>10</sub> sizing cyclone and in-stack filter holder schematic (CFR, 2010) and photograph (//  $\leq 10 \mu\text{m}$ , //  $> 10 \mu\text{m}$ ).

Figure 7 shows the performance curves for the Method 201A sizing cyclones. To measure PM<sub>10</sub>, the method requires selecting a gas sampling nozzle to achieve a sampling rate that produces a cut size between 9.0 and 11.0 mm at the stack gas temperature. For this study, Method 201A was specifically used to collect filterable PM<sub>10</sub> emissions (solid particles emitted by a source at the stack and captured in the ≤ 10 μm wash and on the filter [CFR, 2010]).



**Figure 7. Acceptable sampling rate for sizing cyclones (CFR, 2010) Cyclone I = PM<sub>10</sub> sizing cyclone (gas temperatures for the mote cyclone robber systems ranged from 16 to 39°C [61-102°F]).**

Only one stack from each mote cyclone robber 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 cyclone, was purchased from Apex Instruments (Fuquay-Varina, NC) and met specifications of Method 201A. The sampling media were 47-mm Zeffluor 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 and wash tubs with lids were pre-labeled, 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 calibrated and checked all sampling equipment according to EPA Method 201A.

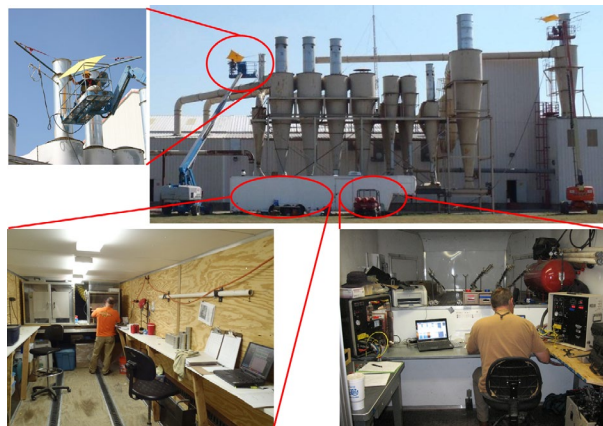
Each cyclone selected for testing was fitted with a cyclone stack extension that incorporated two sampling ports (90° apart) and airflow straightening vanes to eliminate the cyclonic flow of the air exiting the cyclone (Fig. 8). The extensions were designed to meet EPA criteria (EPA, 1989) with an overall 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 straightening 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).



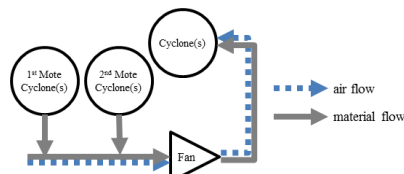
**Figure 9.** Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

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

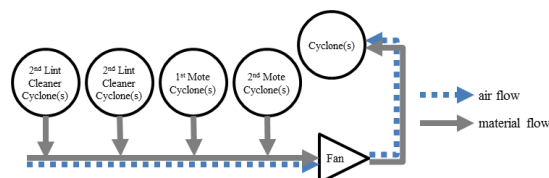
In addition to gravimetric analyses, each sample was visually inspected for unusual characteristics, such as cotton lint content or extraneous material. Digital pictures were taken of all filters and washes for documentation purposes prior to further analyses. After the laboratory analyses were completed, all stack sampling, cotton gin production, and laboratory data were merged.

Three of the seven gins had mote cyclone robber systems. The mote cyclone robber systems sampled were typical for the industry, but varied among the gins. The mote cyclone robber systems at gins A and D pneumatically conveyed lint laden trash from the cyclones for the 1<sup>st</sup> stage mote system and the 2<sup>nd</sup> stage

mote system (waste streams from the 1<sup>st</sup> and 2<sup>nd</sup> stage lint-cleaning systems) through a fan to a cyclone that dropped the trash into a machine for cleaning and packaging (Fig. 10). The mote cyclone robber system at gin B was similar, except it also picked up lint laden trash from the cyclones for two 2<sup>nd</sup> stage lint-cleaner systems (Fig. 11).



**Figure 10.** Schematic of mote cyclone robber system pulling material from the cyclones for 1<sup>st</sup> and 2<sup>nd</sup> stage mote systems (gins A and D).



**Figure 11.** Schematic of mote cyclone robber system pulling material from the cyclones for 1<sup>st</sup> and 2<sup>nd</sup> stage mote systems and two 2<sup>nd</sup> stage lint-cleaning systems (gin B).

All mote cyclone robber systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among the gins (Table 1 and Fig. 12). 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 air stream for gins A and D were exhausted through a single cyclone. Inlets on all the mote cyclone robber cyclones were 2D2D type, except gin A that had an inverted 1D3D inlet. Expansion chambers were present on mote cyclone robber cyclones for gin B. Gins A and D had standard cones. All of the cyclone configurations outlined above, if properly designed and maintained, are recommended for controlling cotton gin emissions (Whitelock et al., 2009).



**Figure 12.** 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.

**Table 1. Abatement device configuration<sup>z</sup> for mote cyclone robber systems tested.**

Gin	Cyclone Type	Inlet Design <sup>y</sup>	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash Exits to <sup>x</sup>
A	1D3D	inverted 1D3D	1	1	single	standard	mote cleaner
B	1D3D	2D2D	1	2	dual	expansion chamber	mote cleaner
D	1D3D	2D2D	1	1	single	standard	mote cleaner

<sup>z</sup> Figures 5 and 12

<sup>y</sup> Inverted 1D3D inlet has duct in line with the bottom of the inlet

<sup>z</sup> Systems to remove material from cyclone trash exits: mote cleaner = gin machine that further cleans fiber captured by system

### RESULTS

Table 2 shows the test parameters for each Method 201A test run for the mote cyclone robber cleaning systems sampled at the three gins. The system average ginning rate was 28.0 bales/h and the test average ginning rates at each gin ranged from 25.5 to 31.5 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. Test run one for gin B was omitted from the test average because of inconsistent gin operation. The 1D3D cyclones were all operated with inlet velocities within design criteria,  $16.3 \pm 2$  m/s ( $3200 \pm 400$  fpm), except the test runs at gin D that 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<sub>10</sub> or total particulate measurements (CFR, 2010). Isokinetic sampling and PM<sub>10</sub> aerodynamic cut size must fall within EPA defined ranges ( $100 \pm 20\%$  and  $10.0 \pm 1.0 \mu\text{m}$ , respectively) for valid PM<sub>10</sub> test runs. All tests met both criteria (Table 2). To use the method to obtain total filterable particulate also, sampling must be within 90 to 110% of isokinetic flow. This criterion was not met in the third test run for gin A 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. Sampling rates ranged from 11.4 to 14.8 standard l/min (0.401-0.523 standard ft<sup>3</sup>/min). The stack gas temperatures ranged from 16 to 39°C (61-102°F).

**Table 2. Cotton gin production data and stack sampling performance metrics for the mote cyclone robber systems.**

Gin	Test Run	Ginning Rate bales/h <sup>z</sup>	Cyclone Inlet Velocity		Isokinetic Sampling %	Aerodynamic Cut Size D <sub>50</sub> PM <sub>10</sub> μm	Sampling Rate <sup>y</sup>		Stack Temperature	
			m/s	fpm			slpm	scfm	°C	°F
A	1	26.0	16.7	3287	93	10.8	11.4	0.401	16	61
	2	27.2	16.8	3313	109	9.7	13.5	0.475	22	71
	3	27.6	17.0	3340	119 <sup>w</sup>	9.1	14.8	0.523	23	74
	<b>Test Average</b>	26.9	16.8	3314						
B	1 <sup>x</sup>	9.9	15.7	3094	95	10.2	12.9	0.456	39	102
	2	21.7	15.6	3069	97	10.1	13.1	0.462	37	99
	3	29.2	15.4	3033	96	10.2	12.7	0.450	37	98
	<b>Test Average</b>	25.5	15.5	3051						
D	1	29.7	18.9	3726	84 <sup>w</sup>	10.3	12.3	0.434	27	81
	2	33.5	19.1	3755	89 <sup>w</sup>	10.2	12.4	0.439	29	84
	3	31.3	18.8	3710	97	10.1	12.7	0.449	30	87
	<b>Test Average</b>	31.5	18.9	3730						
<b>System Average</b>		28.0	17.1	3365						

<sup>z</sup> 227 kg (500 lb) equivalent bales

<sup>y</sup> slpm = standard l/min, scfm = standard ft<sup>3</sup>/min

<sup>x</sup> Test run omitted from test averages because of inconsistent gin operation during test

<sup>w</sup> Did not meet total particulate isokinetic sampling rate criteria ( $100 \pm 10\%$ )

PM<sub>10</sub> emissions data (ginning and emission rates and corresponding emission factors) for the mote cyclone robber systems are shown in Table 3. The system average PM<sub>10</sub> emission factor was 0.028 kg/227-kg bale (0.061 lb/500-lb bale). The test average emission factors ranged from 0.013 to 0.054 kg (0.029-0.119 lb) per bale and emission rates ranged from 0.36 to 1.71 kg/h (0.79-3.77 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the mote cyclone robber systems are shown in Table 4. The system average total particulate emission factor was 0.039 kg/bale (0.087 lb/bale). The test average emission factors ranged from 0.029 to 0.059 kg (0.064-0.130 lb) per bale. The test average total particulate emission rates ranged from 0.74 to 1.84 kg/h (1.62-4.07 lb/h). The ratio of PM<sub>10</sub> to total particulate was 70.5% (ratios calculated using Tables 3 and 4 might vary slightly from those listed due to rounding).

The average mote cyclone robber system total particulate emission factor for this project was about 48% of the EPA AP-42 published value for the cyclone robber system and 31% of the EPA AP-42 published value for the mote fan (EPA, 1996a, b). The range of test average total particulate mote cyclone robber emission factors determined for this project and the range of mote fan AP-42 emission factor data overlapped. The average mote cyclone robber system PM<sub>10</sub> emission factor average for this project was about 1.18 times the EPA AP-42 published value for the cyclone robber system and about 47% of the EPA AP-42 published value for the mote fan. The test average mote cyclone robber system PM<sub>10</sub> emission factor range also overlapped with the AP-42 mote fan emission factor data range.

Figure 13 shows an example of samples recovered from a typical mote cyclone robber system test run. Often, there were cotton lint fibers, which have cross-sectional diameters much greater than 10 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 samples shown in Fig. 14, lint fibers passed through the PM<sub>10</sub> cyclone and collected in the ≤ 10 μm wash and on the filter. This type of material carryover can bias the gravimetric measurements and affect reported PM<sub>10</sub> 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.

**Table 3. PM<sub>10</sub> emissions data for the mote cyclone robber systems.**

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale <sup>z</sup>	lb/bale <sup>z</sup>
A	1	0.34	0.75	0.013	0.029
	2	0.41	0.90	0.015	0.033
	3	0.33	0.72	0.012	0.026
Test Average (n=3)		0.36	0.79	0.013	0.029
B	1 <sup>y</sup>	0.10	0.21	0.010	0.021
	2	0.36	0.79	0.017	0.036
	3	0.46	1.01	0.016	0.035
Test Average (n=2)		0.41	0.90	0.016	0.035
D	1	1.87	4.12	0.063	0.139
	2	2.15	4.75	0.064	0.142
	3	1.11	2.44	0.035	0.078
Test Average (n=3)		1.71	3.77	0.054	0.119
System Average (n=3)				0.028	0.061

<sup>z</sup> 227 kg (500 lb) equivalent bales

<sup>y</sup> Test run omitted from test averages because of inconsistent gin operation during test

**Table 4. Total particulate emissions data for the mote cyclone robber systems.**

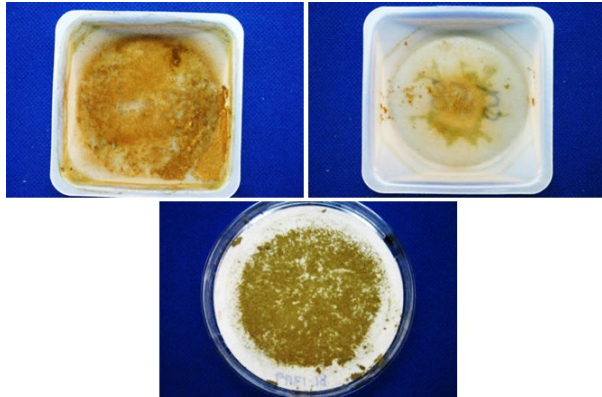
Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale <sup>z</sup>	lb/bale <sup>z</sup>
A	1	0.80	1.76	0.031	0.068
	2	0.83	1.84	0.031	0.068
	3 <sup>x</sup>	0.71	1.56	0.026	0.057
Test Average (n=2)		0.82	1.80	0.031	0.068
B	1 <sup>y</sup>	0.21	0.47	0.021	0.047
	2	0.62	1.37	0.029	0.063
	3	0.85	1.88	0.029	0.064
Test Average (n=2)		0.74	1.62	0.029	0.064
D	1 <sup>x</sup>	2.72	5.99	0.091	0.202
	2 <sup>x</sup>	2.94	6.48	0.088	0.194
	3	1.84	4.07	0.059	0.130
Test Average (n=1)		1.84	4.07	0.059	0.130
System Average (n=3)				0.039	0.087

<sup>z</sup> 227 kg (500 lb) equivalent bales

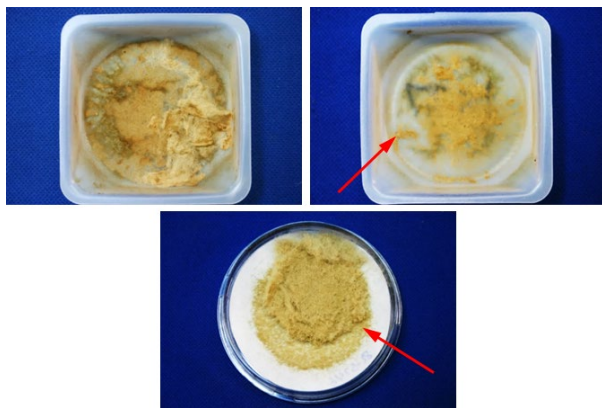
<sup>y</sup> Test run omitted from test averages because of inconsistent gin operation during test

<sup>x</sup> Test run omitted from test averages because isokinetic sampling rate (100 ± 10%) was not met





**Figure 13.** Typical EPA Method 201A filter and sampler head acetone washes from the mote cyclone robber system. Clockwise from top left:  $> 10 \mu\text{m}$  wash,  $\leq 10 \mu\text{m}$  wash, and filter.



**Figure 14.** EPA Method 201A filter and sampler head acetone washes from the mote cyclone robber system with lint fiber in the  $\leq 10 \mu\text{m}$  wash and on the filter (indicated by arrows). Clockwise from top left:  $> 10 \mu\text{m}$  wash,  $\leq 10 \mu\text{m}$  wash, and filter.

### SUMMARY

Seven cotton gins across the U.S. cotton belt were sampled using EPA Method 201A to collect data to fill the data gap that exists for cotton gin emissions data and improve EPA AP-42  $\text{PM}_{10}$  emission factor quality ratings for cotton gins. Three of the seven gins had mote cyclone robber 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 three gins were typical of the industry, averaging 28.0 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  $\leq 10 \mu\text{m}$  samples.

This larger lint material can affect the reported emissions data, but EPA Method 201A does not suggest methods to account for these anomalies. The mote cyclone robber system average emission factors for  $\text{PM}_{10}$  and total particulate were 0.028 kg/227-kg bale (0.061 lb/500-lb bale) and 0.039 kg/bale (0.087 lb/bale), respectively. The gin test average  $\text{PM}_{10}$  and total particulate emission rates ranged from 0.36 to 1.71 kg/h (0.79-3.77 lb/h) and 0.74 to 1.84 kg/h (1.62-4.07 lb/h), respectively. Based on the mote cyclone robber system average emission factors, the ratio of  $\text{PM}_{10}$  to total particulate was 70.5%.

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