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ENGINEERING AND GINNING

Mote Cyclone Robber 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 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, because current EPA AP-42 cotton gin $PM_{2.5}$ emission factors did not exist. The objective of this study is the development of $PM_{2.5}$ emission factors for cotton gin mote cyclone robber systems based on the EPA-approved stack sampling methodology, Method 201A. The project plan included sampling seven cotton gins across the Cotton Belt. Three of the seven gins had mote cyclone robber systems. In terms of capacity, the three gins were typical of the industry, averaging 24.8 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 mote cyclone robber system $PM_{2.5}$ emission factor based on the three tests (five total test runs) was 0.0044 kg/227-kg bale (0.010 lb/500-lb bale). The mote cyclone robber system emission factors for PM_{10} and total particulate were 0.010 kg/bale (0.023 lb/bale) and 0.040 kg/bale (0.087 lb/bale), respectively. The mote cyclone robber system $PM_{2.5}$ emission rate from test averages ranged from 0.038 to 0.24 kg/h (0.084-0.53 lb/h). System average PM_{10} and total particulate emission factors were lower than those currently published in EPA AP-42 for a similar system. The ratios of mote cyclone robber system $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 11.1, 42.5, and 26.2%, respectively.

In 2006, the United States (U.S.) Environmental Protection Agency (EPA) finalized a more stringent standard for particulate matter with a particle diameter less than or equal to a nominal 2.5-µm ($PM_{2.5}$) aerodynamic equivalent diameter (CFR, 2006). The cotton industry's primary concern with this standard was that there were no published cotton gin $PM_{2.5}$ emissions data. Cotton ginners' associations across the Cotton Belt, including the National, Texas, Southern, Southeastern, and California associations, agreed that there is 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 mote cyclone robber systems.

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There are published PM_{10} (particulate matter with a particle diameter less than or equal to a nominal 10-µm aerodynamic equivalent diameter) and total particulate emission factors for cotton gins in EPA's *Compilation of Air Pollution Emission Factors*, AP-42 (EPA, 1996a, 1996b); however, there are no $PM_{2.5}$, emission factors. Although there are no AP-42 average emission factors for mote cyclone robber systems, there are two systems that are similar to the mote cyclone robber: the cyclone robber and the mote fan. The AP-42 average PM_{10} emission factor for the cyclone robber was 0.024 kg (0.052 lb) per 217-kg [480-lb] and the average PM_{10} 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. These PM_{10} emission factors were based on one and six tests, respectively, and were assigned EPA emission factor quality ratings of D; the second lowest possible rating (EPA, 1996a). The AP-42 average total particulate emission factor for the cyclone robber was 0.083 kg (0.18 lb) per bale and the total particulate emission factor for the mote fan was 0.13 kg (0.28 lb) per bale, and ranged from 0.045 to 0.47 kg (0.099-1.0 lb). These total particulate factors were based on one and nine tests, respectively, and were also assigned EPA emission factor quality ratings of D.

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 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 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 U.S. Cotton Belt (Valco et al., 2003, 2006, 2009, 2012).

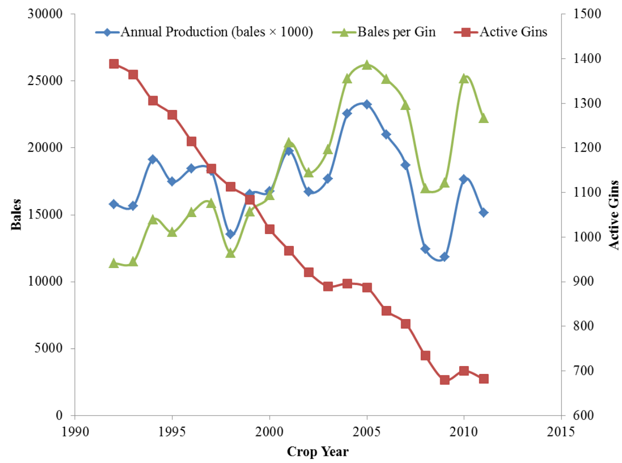

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

Typical cotton gin processing systems include: unloading system, dryers, seed cotton cleaners, gin stands, overflow collector, lint cleaners, battery condenser, bale packaging system, and trash handling systems (Fig. 2); however, the number and type of machines and processes can vary. Each of these systems serves a unique function with the ultimate goal of ginning the cotton to produce a marketable product. Raw seed cotton harvested from the field is compacted into large units called "modules" for delivery to the gin. The unloading system removes seed cotton either mechanically or pneumatically from the module feed system and conveys the seed cotton to the seed cotton cleaning systems. Seed cotton cleaning systems dry the seed cotton and remove foreign matter prior to ginning. Ginning systems also remove foreign matter and separate the cotton fiber from the seed. Lint cleaning systems further clean the cotton lint after ginning. The battery condenser and packaging systems combine lint from the lint cleaning systems and compress the lint into dense bales for efficient transport. Gin systems produce some type of by-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.

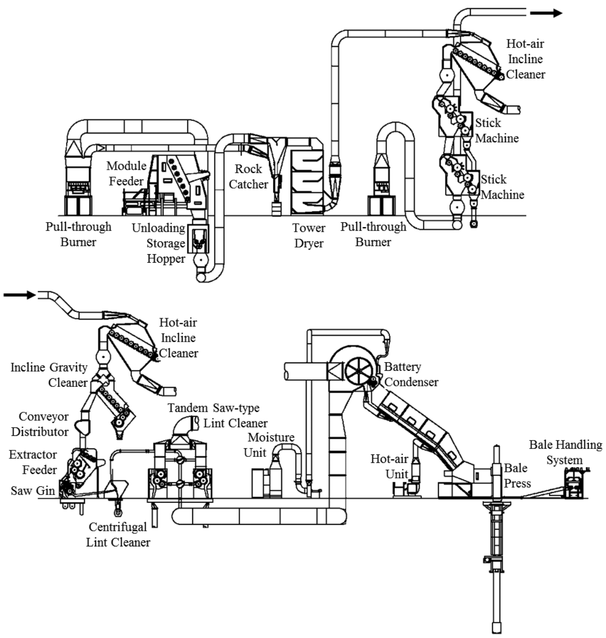

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

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 may also 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 may not be practical to convey the high-lint-content material mechanically, as the 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 slightly. 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).

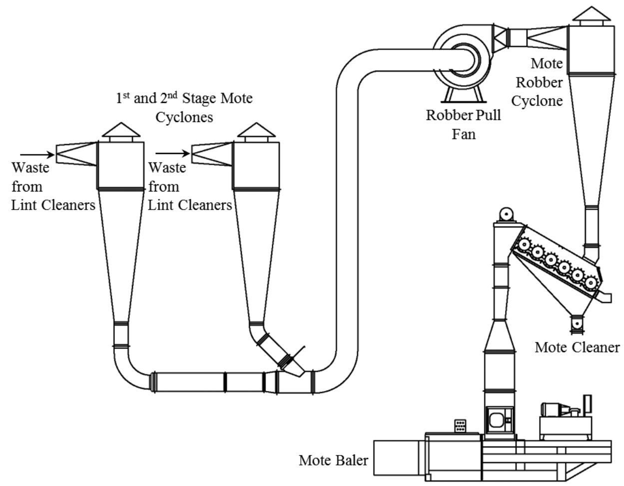

Figure 3. Typical cotton gin mote cyclone robber system layout (Courtesy Lummus Corporation, Savannah, GA).

Figure 4. Photograph of typical trash captured by the mote cyclone robber cyclones.

Cyclones are the most common particulate matter abatement devices used at cotton gins. Standard cyclone designs used at cotton ginning facilities are the 2D2D and 1D3D (Whitelock et al., 2009). The first D in the designation indicates the length of the cyclone barrel relative to the cyclone barrel diameter and the second D indicates the length of the cyclone cone relative to the cyclone barrel diameter. A standard 2D2D cyclone (Fig. 5) has an inlet height of D/2 and width of D/4 and design inlet velocity of 15.2 ± 2 m/s (3000 ± 400 fpm). The standard 1D3D cyclone (Fig. 5) has the same inlet dimensions as the 2D2D or 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).

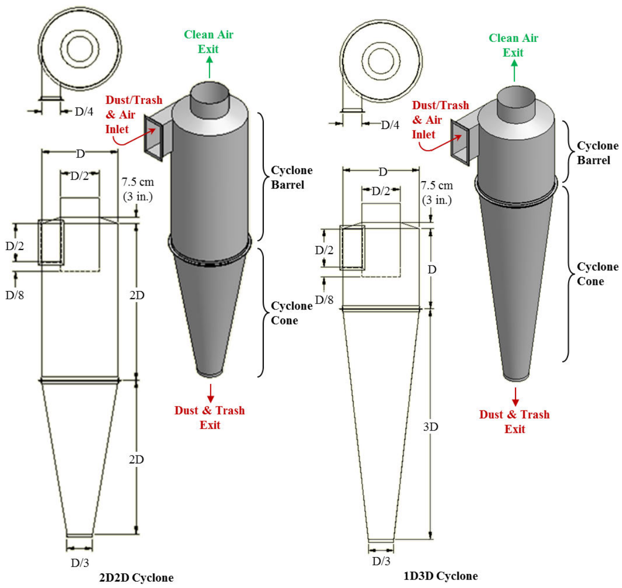

Figure 5. 2D2D and 1D3D cyclone schematics.

The objective of this study is the development of $PM_{2.5}$ emission factors for cotton gin mote cyclone robber systems with cyclones for emissions control based on EPA-approved stack sampling methodologies.

METHODS

Two advisory groups were established for this project. The industry group consisted of cotton ginning industry leaders and university and government researchers. The air quality group included members from state and federal regulatory agencies and university and government researchers. Both groups were formed to aid in project planning, gin selection, data analyses, and reporting. The project plan 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 mote cyclone robber system at each gin. When testing for this project began in 2008, OTM27 was the EPA method for determination of PM_{10} and $PM_{2.5}$ from stationary sources. In December 2010, OTM27 was replaced with a revised and finalized Method 201A (CFR, 2010). The revised Method 201A was a successor to OTM27. The two methods were similar to the point that EPA stated in an answer to a frequently asked question for Method 201A (EPA, 2010) that "If the source was using OTM 27 (and 28) for measuring either PM_{10} or $PM_{2.5}$ then using the revised reference methods Method 201A (and 202) should not be a concern and should give equivalent results." Accordingly, OTM27 is no longer an EPA method that can be cited, and the revised Method 201A will be cited in this manuscript. Using Method 201A to sample $PM_{2.5}$, the particulate-laden stack gas was withdrawn isokinetically (the velocity of the gas entering the sampler was equal to the velocity of the gas in the stack) through a PM_{10} sizing cyclone and a $PM_{2.5}$ sizing cyclone, and then collected on an in-stack filter (Fig. 6). The methods for retrieving the filter and conducting acetone washes of the sizing cyclones are described in detail in Method 201A (CFR, 2010). The mass of each size fraction was determined by gravimetric analysis and included: > 10 µm (PM_{10} sizing cyclone catch acetone wash); 10 to 2.5 µm (PM_{10} sizing cyclone exit acetone wash and $PM_{2.5}$ sizing cyclone catch acetone wash); and ≤ 2.5 µm ($PM_{2.5}$ sizing cyclone exit acetone wash and filter). The $PM_{2.5}$ mass was determined by adding the mass of particulates captured on the filter and the ≤ 2.5 µm wash. The PM_{10} mass was determined by adding the $PM_{2.5}$ mass and the mass of the 10 to 2.5 µm wash. Total particulate was determined by adding the PM_{10} mass and the mass of the > 10 µm wash.

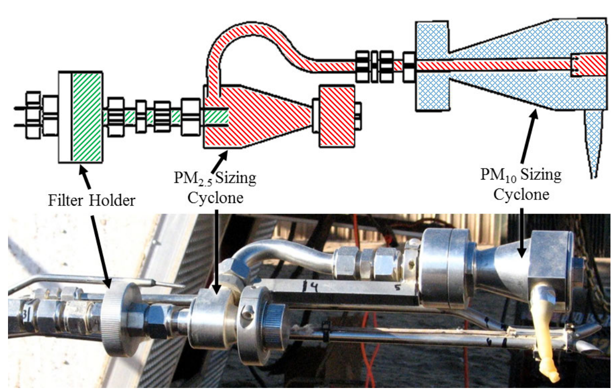

Figure 6. EPA Method 201A PM_{10} and $PM_{2.5}$ sizing cyclones and in-stack filter holder schematic (CFR, 2010) and photograph (≤ 2.5 µm, 10 to 2.5 µm, > 10 µm).

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.

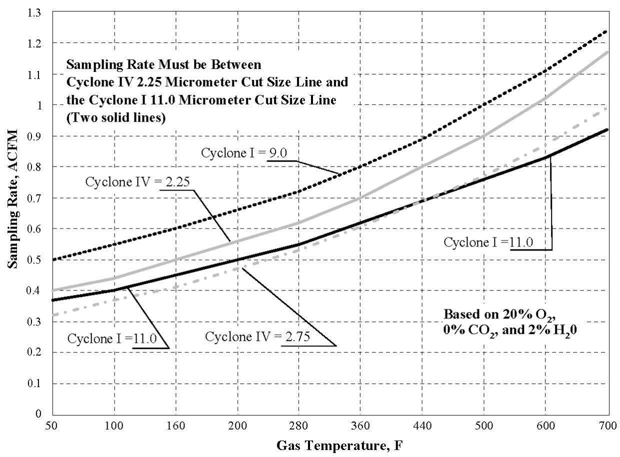

Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = PM_{10} sizing cyclone and Cyclone IV = $PM_{2.5}$ sizing cyclone (Gas temperatures from the mote cyclone robber systems tested ranged from 21 to 39˚C [70-102˚F]).

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 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 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 straightening vanes and 0.9-m (36-in) upstream from the extension exit.

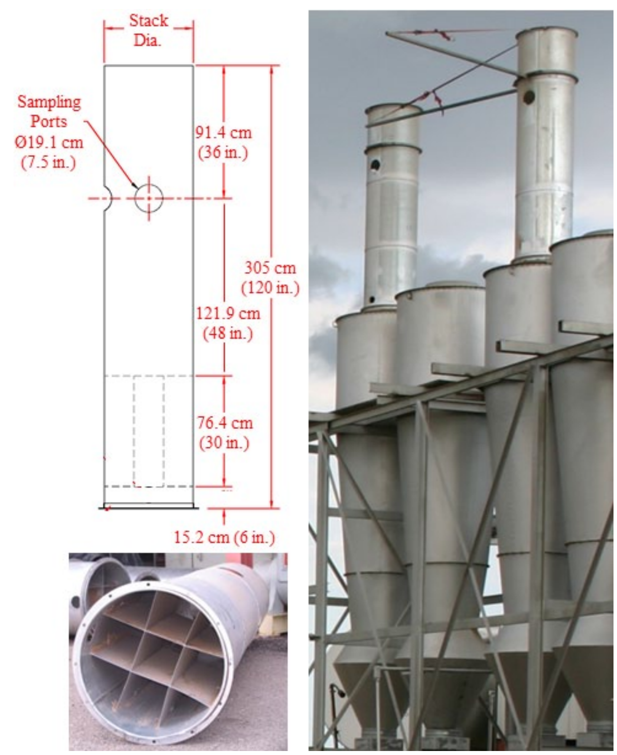

Figure 8. Schematic and photographs of stack extensions with sampling ports and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

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 American Society of Agricultural and Biological Engineers (ASABE) Standard S582 (ASABE, 2005).

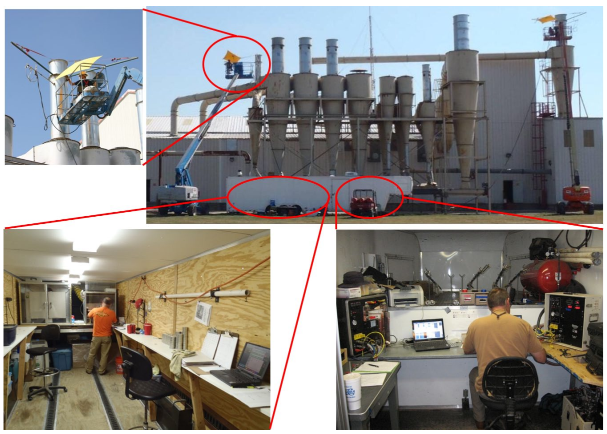

Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber (21 ± 2°C [70 ± 3.6°F]; 35 ± 5% RH) for 48 h prior to gravimetric analyses. Filters were weighed in the environmental chamber on a Mettler MX-5 microbalance (Mettler-Toledo Inc., Columbus, OH – 1 µg readability and 0.9 µg repeatability) after being passed through an 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.

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 system at gins A and D pneumatically conveyed lint laden trash from the cyclones for the first-stage mote system and the second-stage mote system (waste streams from the first and second-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 second-stage lint cleaner systems (Fig. 11).

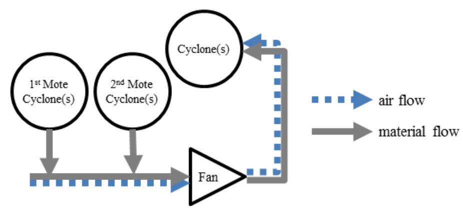

Figure 10. Schematic of mote cyclone robber system pulling material from the cyclones for the first and second-stage mote systems (gins A and D).

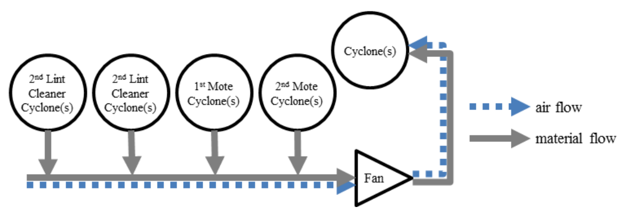

Figure 11. Schematic of mote cyclone robber system pulling material from the cyclones for the first and second-stage mote systems and two 2nd stage lint cleaner systems (gin B).

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 which 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 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 mote cyclone robber 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	mote cleaner
B	1D3D	2D2D	1	2	dual	expansion chamber	mote cleaner
D	1D3D	2D2D	1	1	single	standard	mote cleaner

[z] Figures 5 and 12

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

[x] Systems to remove material from cyclone trash exits: mote cleaner = gin machine that further cleans fiber captured by system

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.

RESULTS

Table 2 shows the test parameters for each Method 201A test run for the mote cyclone robber systems sampled at the three gins. The system average ginning rate was 24.8 bales/h and the test average ginning rates at each gin ranged from 23.7 to 26.9 bales/h (based on 227-kg [500-lb] equivalent bales). Gin D test runs two and three were not included in test averages because of inconsistent gin operation. 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).

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

Gin	Test Run	Ginning Rate, bales/h[z]	Cyclone Inlet Velocity,		Isokinetic Sampling, %	Aerodynamic Cut Size D_{50},		Sampling Rate[y]		Stack Temperature	
			m/s	fpm		$PM_{2.5}$ µm	PM_{10} µm	slpm	scfm	°C	°F
A	1	25.3	15.4	3030	102	2.51	11.0	11.5	0.407	28	82
	2	18.9	16.1	3166	102	2.33	10.6	12.1	0.426	24	75
	3	26.8	16.4	3221	108	2.10[u]	10.0	13.1	0.461	23	73
Test Average		23.7	15.9	3139							
B	1	26.8	15.1	2976	86[v]	2.49	11.2[u]	11.1	0.393	35	95
	2	27.5	14.8	2918	102	2.50	11.2[u]	11.2	0.395	38	100
	3	26.5	14.6	2882	121[vw]	2.11[u]	10.1	13.1	0.461	39	102
Test Average		26.9	14.9	2925							
D	1	23.9	15.7	3090	104	2.55	11.5[u]	10.3	0.362	21	70
	2[x]	5.2	17.7	3487	83[v]	2.55	11.5[u]	10.3	0.365	23	73
	3[x]	13.7	16.8	3310	103	2.43	11.1[u]	10.9	0.385	26	79
Test Average		23.9	15.7	3090							
System Average		24.8	15.5	3052							

[z] 227 kg (500 lb) equivalent bales

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

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

[w] Did not meet $PM_{2.5}$ or PM_{10} isokinetic sampling rate criteria (100 ± 20%)

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

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

There are criteria specified in EPA Method 201A for test runs to be valid for $PM_{2.5}$, PM_{10}, or total particulate measurements (CFR, 2010). Isokinetic sampling must fall within EPA defined ranges (100 ± 20%) for valid $PM_{2.5}$ and PM_{10} test runs. All tests met the isokinetic criteria (Table 2), except gin B test run three. Thus, the data associated with run three of the gin B test were omitted from the $PM_{2.5}$ and PM_{10} test averages. 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 first or third test runs for gin B or the second test run 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 either gin A or B, thus the data associated with these runs were omitted from the 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 first or second test runs for gin B or the first, second or third test runs for gin D, thus the data associated with these runs were omitted from the PM_{10} test averages.

Sampling rates ranged from 10.3 to 13.1 standard l/min (0.36-0.46 standard ft^3/min) (Table 2). The stack gas temperatures ranged from 21 to 39°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.

The $PM_{2.5}$ emissions data (ginning and emission rates and corresponding emission factors) for the mote cyclone robber system are shown in Table 3. The system average $PM_{2.5}$ emission factor was 0.0044 kg/bale (0.010 lb/bale). The test average emission factors at each gin ranged from 0.0015 to 0.010 kg (0.0034-0.022 lb) per bale and test average $PM_{2.5}$ emission rates ranged from 0.038 to 0.24 kg/h (0.084-0.53 lb/h). PM_{10} emissions data (ginning and emission rates and corresponding emission factors) for the mote cyclone robber system are shown in Table 4. The system average PM_{10} emission factor was 0.010 kg/bale (0.023 lb/bale) and the test average PM_{10} emission rate was 0.24 kg/h (0.54 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the mote cyclone robber are shown in Table 5. The system average total particulate emission factor was 0.040 kg/bale (0.087 lb/bale). The test average emission factors ranged from 0.021 to 0.076 kg (0.047-0.17 lb) per bale. Test average total particulate emission rates ranged from 0.51 to 1.82 kg/h (1.11-4.00 lb/h). The ratios of $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 11.1, 42.5, and 26.2%, respectively (ratios calculated using tables 3, 4, and 5 may vary slightly from those listed due to rounding).

The mote cyclone robber system total particulate emission factor average for this project was about 48.4% of the EPA AP-42 published value for the cyclone robber (EPA, 1996a, 1996b). A cyclone robber system is different than a mote cyclone robber system, but the cyclone robber system listed in EPA AP-42 is the closest system design to a mote cyclone robber 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 mote cyclone robber system PM_{10} emission factor average for this project was 26.2% of the EPA AP-42 published value for the cyclone robber system. The test average PM_{10} emission factor range also overlapped with AP-42 emission factor data range.

Table 3. $PM_{2.5}$ emissions data for the mote cyclone robber system.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.047	0.10	0.0019	0.0041
	2	0.029	0.063	0.0015	0.0033
	3[y]	0.031	0.069	0.0012	0.0026
Test Average (n=2)		0.038	0.084	0.0017	0.0037
B	1	0.057	0.12	0.0021	0.0046
	2	0.026	0.057	0.00095	0.0021
	3[y]	0.018	0.040	0.00069	0.0015
Test Average (n=2)		0.041	0.091	0.0015	0.0034
D	1	0.24	0.53	0.010	0.022
	2[x]	0.11	0.24	0.021	0.046
	3[x]	0.20	0.44	0.014	0.032
Test Average (n=1)		0.24	0.53	0.010	0.022
System Average (n=3)				0.0044	0.010

[z] 227 kg (500 lb) equivalent bales

[y] Test run omitted from test averages because isokinetic sampling rate (100 ± 20%) and/or aerodynamic cut size (2.50 ± 0.25 µm) were not met

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

Table 4. PM_{10} emissions data for the mote cyclone robber system.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.38	0.83	0.015	0.033
	2	0.19	0.42	0.010	0.022
	3	0.17	0.37	0.0062	0.014
Test Average (n=3)		0.24	0.54	0.010	0.023
B	1[y]	0.42	0.92	0.016	0.034
	2[y]	0.33	0.72	0.012	0.026
	3[y]	0.26	0.58	0.010	0.022
Test Average (n=0)					
D	1[y]	1.24	2.73	0.052	0.11
	2[xy]	0.39	0.85	0.074	0.16
	3[xy]	0.78	1.72	0.057	0.13
Test Average (n=0)					
System Average (n=1)				0.010	0.023

[z] 227 kg (500 lb) equivalent bales

[y] Test run omitted from test averages because isokinetic sampling rate (100 ± 20%) and/or aerodynamic cut size (10.0 ± 1.0 µm) were not met

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

Table 5. Total particulate emissions data for the mote cyclone robber system.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.83	1.83	0.033	0.072
	2	0.39	0.86	0.021	0.045
	3	0.29	0.65	0.011	0.024
Test Average (n=3)		0.51	1.11	0.021	0.047
B	1[y]	0.70	1.53	0.026	0.057
	2	0.58	1.28	0.021	0.047
	3[y]	0.44	0.96	0.016	0.036
Test Average (n=1)		0.58	1.28	0.021	0.047
D	1	1.82	4.00	0.076	0.17
	2[x]	0.52	1.15	0.10	0.22
	3[x]	1.02	2.25	0.075	0.16
Test Average (n=1)		1.82	4.00	0.076	0.17
System Average (n=3)				0.040	0.087

[z] 227 kg (500 lb) equivalent bales

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

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

Figure 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 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 test run shown in Fig. 14, lint fibers passed through the PM_{10} cyclone 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 13. Typical EPA Method 201A filter and sampler head acetone washes from the mote cyclone robber system. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

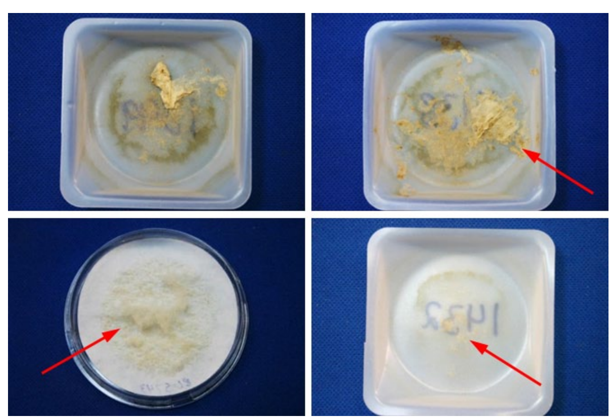

Figure 14. Atypical EPA Method 201A filter and sampler head acetone washes from the mote cyclone robber system with lint fiber in the 10 to 2.5 µm wash and ≤ 2.5 µm wash , and on filter. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

SUMMARY

Seven cotton gins across the U.S. Cotton Belt were stack sampled using EPA Method 201A to fill the data gap that exists for $PM_{2.5}$ cotton gin emissions data. 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 24.8 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 mote cyclone robber system $PM_{2.5}$ emission factor based on the three gins tested (five total test runs) was 0.0044 kg/227-kg bale (0.010 lb/500-lb bale). The mote cyclone robber system emission factors for PM_{10} and total particulate were 0.010 kg/bale (0.023 lb/bale) and 0.040 kg/bale (0.087 lb/bale), respectively. The gin test average $PM_{2.5}$ and total particulate emission rates ranged from 0.038 to 0.24 kg/h (0.084-0.53 lb/h) and 0.51 to 1.82 kg/h (1.11-4.00 lb/h), respectively, and the PM_{10} test average emission rate was 0.24 kg/h (0.54 lb/h). System average PM_{10} and total particulate emission factors were lower than those currently published in EPA AP-42 for a similar system. The ratios of mote cyclone robber system $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 11.1, 42.5, and 26.2%, respectively. These data are the first published data to document $PM_{2.5}$ emissions from mote cyclone robber systems at cotton gins.

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DISCLAIMER

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