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ENGINEERING AND GINNING

First Stage Seed-Cotton Cleaning System $PM_{2.5}$ Emission Factors and Rates for Cotton Gins: Method 201A Combination PM_{10} and $PM_{2.5}$ Sizing Cyclones

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ABSTRACT

This report is part of a project to characterize cotton gin emissions from the standpoint of stack sampling. In 2006, EPA finalized and published a more stringent standard for particulate matter with nominal diameter less than or equal to 2.5 µm ($PM_{2.5}$). This created an urgent need to collect additional cotton gin emissions data to address current regulatory issues, because current EPA AP-42 cotton gin $PM_{2.5}$ emission factors did not exist. The objective of this study was the development of $PM_{2.5}$ emission factors for cotton gin 1st stage seed-cotton cleaning systems based on the EPA-approved stack sampling methodology, Method 201A. The project plan included sampling seven cotton gins across the cotton belt. Key factors for selecting specific cotton gins included: 1) facility location (geographically diverse), 2) industry representative production capacity, 3) typical processing systems and 4) equipped with properly designed and maintained 1D3D cyclones. All seven gins had 1st stage seed cotton cleaning systems. In terms of capacity, the seven 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 1st stage seed-cotton cleaning system $PM_{2.5}$ emission factor based on the seven tests (19 total test runs) was 0.0083 kg/227-kg bale (0.018 lb/500-lb bale). The 1st stage seed-cotton cleaning system average emission factors for PM_{10} and total particulate were 0.074 kg/bale (0.162 lb/bale) and 0.101 kg/bale (0.222 lb/bale), respectively. The 1st stage seed-cotton cleaning system $PM_{2.5}$ emission rate from test averages ranged from 0.15 to 0.37 kg/h (0.32-0.82 lb/h). System average PM_{10} emission factors were higher and system average total particulate emission factors were lower than those currently published in EPA AP-42. The ratios of 1st stage seed-cotton cleaning system $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 8.3, 11.3, and 73.3%, respectively.

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In 2006, the U.S. Environmental Protection Agency (EPA) finalized a more stringent standard for particulate matter with a particle diameter less than or equal to a nominal 2.5-µm ($PM_{2.5}$) aerodynamic equivalent diameter (CFR, 2006). The cotton industry's primary concern with this standard was that there were no published cotton gin $PM_{2.5}$ emissions data. Cotton ginners' associations across the cotton belt, including the National, Texas, Southern, Southeastern, and California associations, agreed that there was an urgent need to collect $PM_{2.5}$ cotton gin emissions data to address the implementation of the $PM_{2.5}$ standards. Working with cotton ginning associations across the country 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, 1st stage seed-cotton cleaning, 2nd stage seed-cotton cleaning, 3rd stage seed-cotton cleaning, overflow, 1st stage lint cleaning, 2nd stage lint cleaning, combined lint cleaning, cyclone robber, 1st stage mote, 2nd stage mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser, and master trash. This report focuses on $PM_{2.5}$ emissions from 1st stage seed-cotton cleaning systems.

There are published PM_{10} (particulate matter with a particle diameter less than or equal to a nominal 10-µm aerodynamic equivalent diameter) and total particulate emission factors for cotton gins in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996a, 1996b); however, there are no $PM_{2.5}$ emission factors. The AP-42 average PM_{10} emission factor for the No. 1 dryer and cleaner, which is an equivalent system to the 1st stage seed-cotton cleaning system, was 0.055 kg (0.12 lb) per 217-kg (480-lb) equivalent bale with a range of 0.039 to 0.0.96 kg (0.088 to 0.21 lb) per bale. The AP-42 average total particulate emission factor was 0.17 kg (0.36 lb) per bale with a range of 0.11 to 0.25 kg (0.24 to 0.54 lb) per bale. These PM_{10} and total factors were based on five and seven 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 U.S. cotton production remained generally flat at about 17 million bales per year during the last 20 years, production from one year to the next often varied greatly for various reasons, including climate and market pressure (Fig. 1). The number of active gins in the U.S. has not remained constant, steadily declining to less than 700 in 2011. Consequently, the average volume of cotton handled by each gin has risen and gin capacity has increased to an average of about 25 bales per hour across the U.S. cotton belt (Valco et al., 2003, 2006, 2009, 2012).

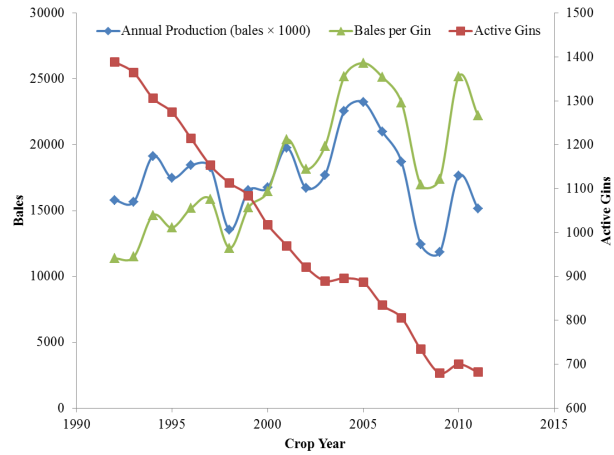

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

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 cotton 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.

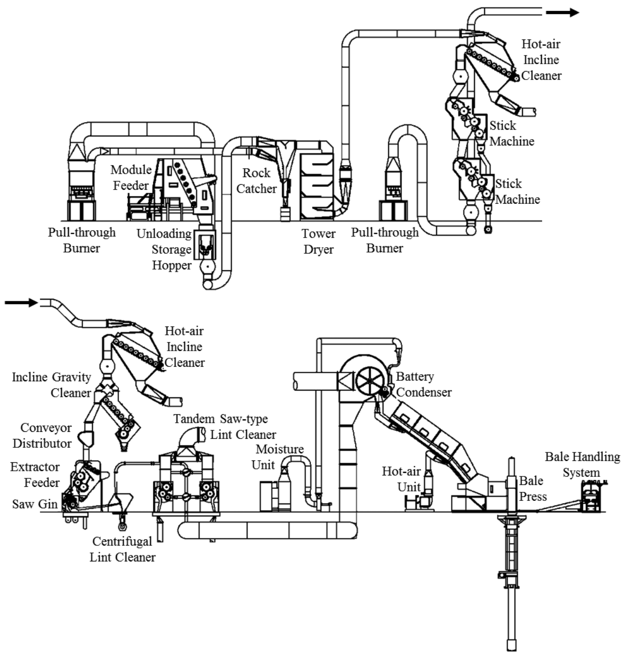

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

The seed cotton is cleaned and dried in the seed-cotton cleaning systems. In the typical 1^{st} stage seed-cotton cleaning system (Fig. 3), seed cotton is pneumatically conveyed with heated air from either the feed control or module feeder through a dryer to the seed-cotton cleaning machinery. The seed cotton is pulled directly into the seed-cotton cleaning machinery and separated from the conveying airstream by the cleaning mechanism (called a “hot-air” cleaner) or separated from the conveying air via a screened separator and dropped into the cleaning machinery. Seed-cotton cleaning machinery includes cleaners or extractors. Each stage often employs two cleaners in series. This system removes foreign matter that includes rocks, soil, sticks, hulls, and leaf material. The airstream from the 1^{st} stage seed-cotton cleaning system continues through a centrifugal fan to an abatement system; generally one or more cyclones. This cleaning system may use air heated up to 117ºC (350ºF) at the seed cotton and air mixing point to accomplish drying during transport (ASABE, 2007). Based on system configuration, the airstream temperature at the abatement device could range from ambient to about 50% of the mixing-point temperature. The material handled by the abatement system is typically the same as that removed by the seed-cotton cleaning machinery (rocks, soil, sticks, hulls, and leaf material) and lint extracted with the trash (Fig. 4).

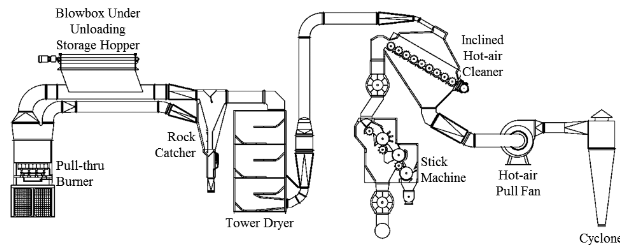

Figure 3. Typical cotton gin 1^{st} stage seed-cotton cleaning system layout (Courtesy Lummus Corporation, Savannah, GA).

Figure 4. Photograph of typical trash captured by the 1^{st} stage seed-cotton cleaning system cyclones.

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

The objective of this study was the development of $PM_{2.5}$ emission factors for cotton gin 1^{st} stage seed-cotton cleaning systems with cyclones for emissions control based on EPA-approved stack sampling methodologies.

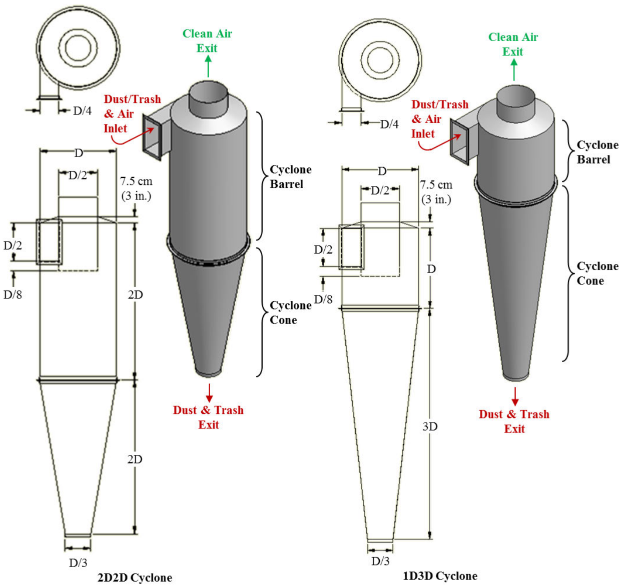

Figure 5. 2D2D and 1D3D cyclone schematics.

METHODS

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

Seven gins were sampled across the cotton belt. Key factors for selecting specific cotton gins included: 1) facility location (geographically diverse), 2) industry representative production capacity, 3) typical processing systems, and 4) equipped with properly designed and maintained 1D3D cyclones. Operating permits, site plans, and aerial photographs were reviewed to evaluate potential sites. On-site visits were conducted on all candidate gins to evaluate the process systems and gather information including system condition, layout, capacities, and standard operation. Using this information, several gins from each selected geographical region were selected and prioritized based on industry advisory group discussions. Final gin selection from the prioritized list was influenced by crop limitations and adverse weather events in the region.

Based on air quality advisory group consensus, EPA Other Test Method 27 (OTM27) was used to sample the 1st stage seed-cotton cleaning 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.

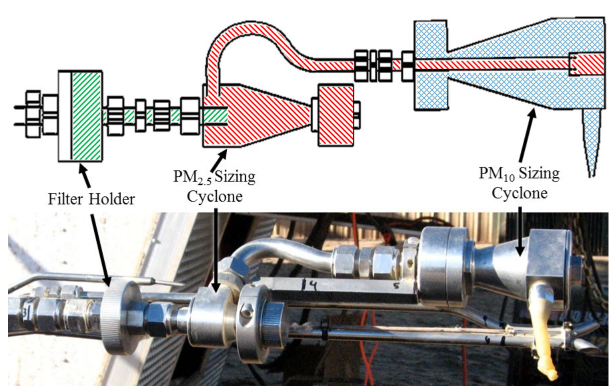

Figure 6. EPA Method 201 A PM_{10} and $PM_{2.5}$ sizing cyclones and in-stack filter holder schematic (CFR, 2010) and photograph (≤ 2.5 µm, 10 to 2.5 µm, > 10 µm).

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. Only one stack from each system was tested.

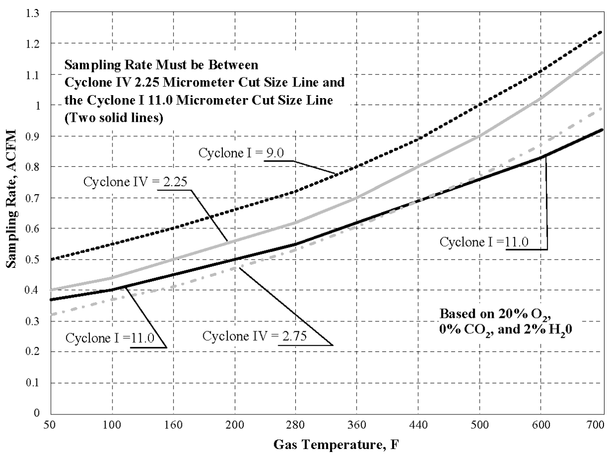

Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = PM_{10} sizing cyclone and Cyclone IV = $PM_{2.5}$ sizing cyclone (Gas temperatures for the 1st stage seed cotton cleaning systems tested ranged from 19 to 70°C [65-158°F]).

For 1st stage seed cotton cleaning 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.

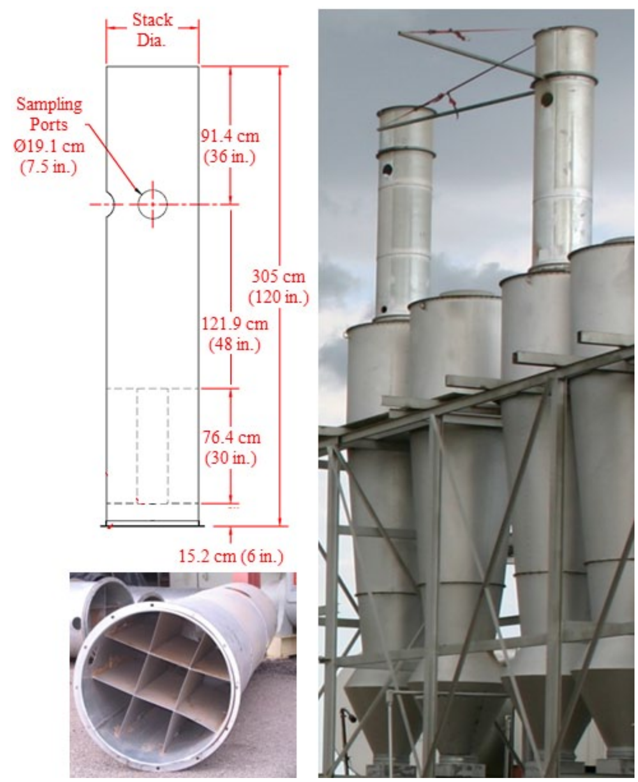

Figure 8. Schematic and photographs of stack extensions with sampling ports and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

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 protocols. 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 pre-weighed lids and placed in individual plastic bags for transport to the AQL in Lubbock, TX for gravimetric analyses. During testing, bale data (ID number, weight, and date/time of bale pressing) were either manually recorded by the bale press operator or captured electronically by the gin's computer system for use in calculating emission factors in terms of kg/227-kg bale (lb/500-lb bale). Emission factors and rates were calculated in accordance with Method 201A and ASAE Standard S582 (ASABE, 2005).

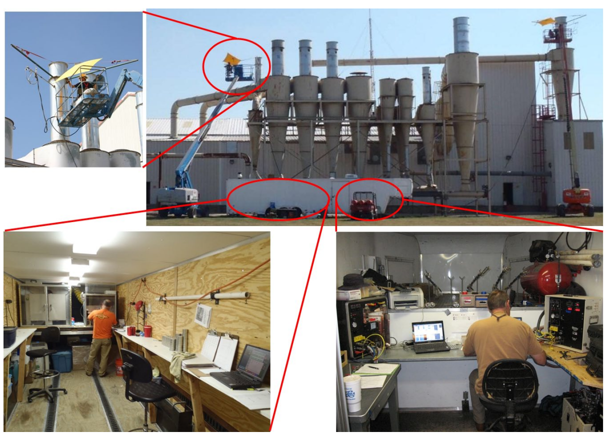

Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests;sample recovery in trailer clean room; technician operating the probe at stack level.

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.

All seven gins had 1st stage seed cotton cleaning systems. The 1st stage seed-cotton cleaning systems sampled were typical for the industry. Gins B, E, and G had similar 1st stage seed-cotton cleaning systems (Fig. 10). The seed-cotton material was pneumatically conveyed from the module feeder to a series of seed-cotton cleaners. The material was separated from the airstream by the first cleaner. The air then passed through a fan and exhausted through one or more cyclones. The gin A system used a feed control unit to regulate the flow of seed cotton (Fig. 11). The material was conveyed pneumatically from the feed control unit through a dryer then the material stream was split. The air was separated from each stream by the first set of parallel cleaners. The two airstreams then merged and passed through a fan and exhausted through one or more cyclones. The 1st stage seed-cotton cleaning systems at gins D and F were similar to the systems at gins B, E, and G except the material stream was split into two parallel systems after the feed control or module feeder (Fig. 12). The 1st stage seed-cotton cleaning system for gin C was similar to the system at gin F except there were separate feed control units for the parallel systems (Fig. 13).

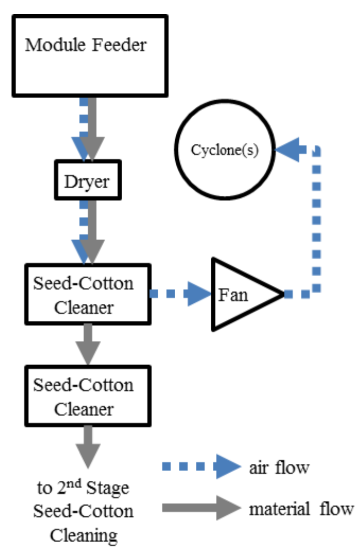

Figure 10. Schematic of single stream/single fan 1st stage seed-cotton cleaning system fed directly by a module feeder (gins B, E, and G).

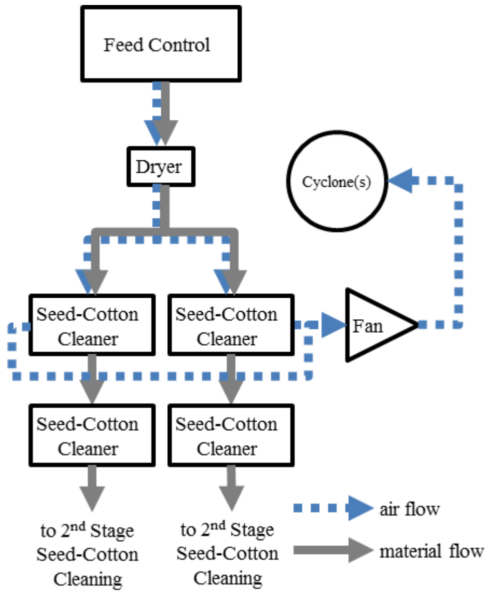

Figure 11. Schematic of split stream/single fan 1st stage seed-cotton cleaning system fed by a feed control (gin A).

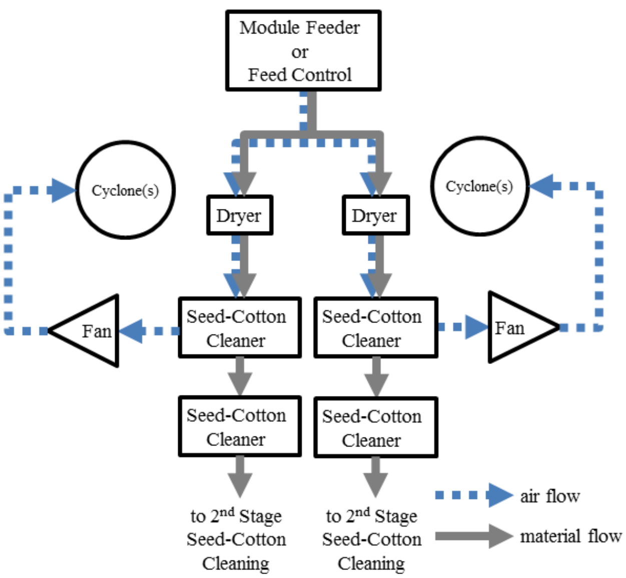

Figure 12. Schematic of split stream/double fan 1st stage seed-cotton cleaning system fed by a feed control (gin D) or fed directly by a module feeder (gin F).

All 1st stage seed-cotton cleaning 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 E, 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 E was exhausted through a single cyclone. Inlets on all the 1st stage seed-cotton cleaning cyclones were 2D2D type, except gin C that had inverted 1D3D inlets. Expansion chambers were present on 1st stage seed-cotton cleaning cyclones at all gins, except gins E and F, which 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). The cyclones at gin F had angle-iron welded inside and down the length of the cone (Fig. 15). This is occasionally done by cyclone manufacturers for systems with high particulate loading, especially sand, to encourage material to exit the cyclone more quickly and reduce cone wear; this is not a recommended practice.

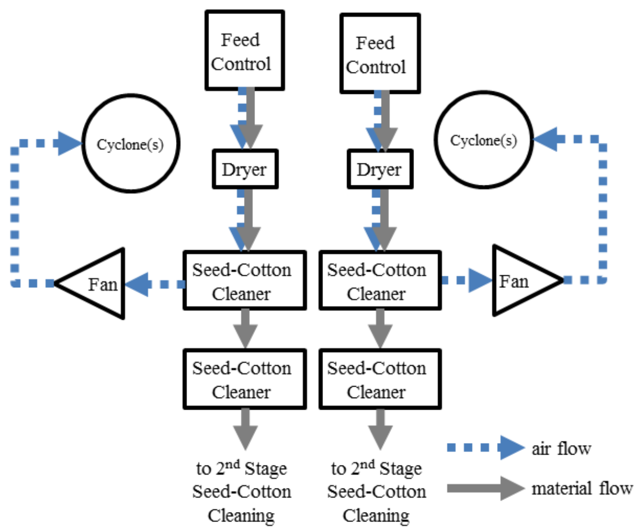

Figure 13. Schematic of completely separate split stream/double fan 1st stage seed-cotton cleaning system fed by a feed control (gin C).

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 inverted1D3D inlet; 1D3D cyclone with 2D2D inlet and expansion chamber on the cone; 1D3D cyclone with 2D2D inlet and standard cone.

Table 1. Abatement device configuration[z] for 1st stage seed-cotton cleaning systems tested.

Gin	Cyclone Type	Inlet Design[y]	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash exits to[x]
A	1D3D	2D2D	1	2	Dual	expansion chamber	Hopper
B	1D3D	2D2D	1	2	Dual	expansion chamber	Auger
C	1D3D	Inverted 1D3D	2	4	Dual	expansion chamber	Hopper
D	1D3D	2D2D	2	4	Dual	expansion chamber	Hopper
E	1D3D	2D2D	1	1	Single	standard	Auger
F	1D3D	2D2D	2	4	Dual	standard	Auger
G	1D3D	2D2D	1	2	Dual	expansion chamber	Auger

[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; auger = enclosed, screw-type conveyor

Figure 15. Angle-iron welded to the inside surface of cyclone cone at gin F.

RESULTS

Table 2 shows the test parameters for each Method 201A test run for the 1st stage seed-cotton cleaning systems sampled at the seven gins. The system average ginning rate was 30.0 bales/h and the test average ginning rates at each gin ranged from 19.9 to 45.8 bales/h (based on 227-kg [500-lb] equivalent bales). The capacity of gins sampled was representative of the industry average, approximately25 bales/h. The 1D3D cyclones were all operated with inlet velocities within design criteria, 16.3 ± 2 m/s (3200 ± 400 fpm), except the test runs at gin C and two runs at gin E 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 $PM_{2.5}$, PM_{10}, or total particulate measurements (CFR, 2010). Isokinetic sampling must fall within EPA defined ranges (100 ± 20%) for valid $PM_{2.5}$ and PM_{10} test runs. All tests met the isokinetic criteria (Table 2). To use the method to also obtain total filterable particulate, sampling must be within 90 to 110% of isokinetic flow. This criteria was not met in the second and third test runs for gin A, in the third test run 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 µm) for valid $PM_{2.5}$ test runs. $PM_{2.5}$ cut size criteria were not met in the third test run for either gin B or C, 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 µm) for valid PM_{10} test runs. PM_{10} cut size criteria were not met in the first test run for gin A, the second test run for gin B, or the second and third test run for gin G, thus the data associated with these runs were omitted from the PM_{10} test averages.

Sampling rates ranged from 11.1 to 13.7 standard l/min (0.39-0.48 standard ft^3/min). The stack gas temperatures ranged from 19 to 70°C (65-158°F). The sampling method documentation (CFR, 2010) warns that the acceptable gas sampling rate range is limited at the stack gas temperatures encountered during this project's testing, as indicated by the narrow difference between the solid lines in 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 2. Cotton gin production data and stack sampling performance metrics for the 1st stage seed-cotton cleaning 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	26.8	17.0	3355	106	2.56	11.2^w	11.1	0.392	22	71
	2	15.0	18.3	3594	88^x	2.31	10.6	11.9	0.420	19	65
	3	22.9	17.7	3476	111^x	2.35	10.7	12.1	0.426	26	78
Test Average		21.6	17.7	3475							
B	1	11.5	17.3	3404	95	2.35	10.8	11.9	0.419	40	104
	2	23.0	16.7	3292	106	2.59	11.4^w	11.1	0.392	43	110
	3	25.2	17.4	3423	99	2.20^w	10.4	12.7	0.449	44	112
Test Average		19.9	17.1	3373							
C	1	23.7	13.6	2671	103	2.41	10.8	12.5	0.441	58	137
	2	25.4	13.2	2607	105	2.42	10.9	12.5	0.440	59	138
	3	25.2	13.7	2703	111^x	2.20^w	10.3	13.5	0.476	58	137
Test Average		24.8	13.5	2660							
D	1	32.9	15.6	3076	97	2.39	10.9	11.8	0.416	42	108
	2	35.0	15.6	3066	99	2.40	10.9	11.9	0.421	46	115
	3	31.1	15.8	3120	99	2.34	10.8	12.1	0.429	46	114
Test Average		33.0	15.7	3087							
E	1	24.4	19.7	3879	100	2.29	10.6	12.4	0.437	44	112
	2	27.9	19.1	3768	103	2.31	10.6	12.3	0.435	44	112
	3	36.8	18.3	3597	93	2.33	10.7	12.5	0.442	50	123
Test Average		29.7	19.0	3748							
F	1	41.9	16.2	3195	109	2.35	10.5	13.7	0.483	66	151
	2	45.2	16.7	3281	102	2.44	10.8	13.2	0.466	65	149
	3	50.3	16.1	3160	109	2.43	10.7	13.5	0.477	70	158
Test Average		45.8	16.3	3212							
G	1	35.4	15.8	3109	119^x	2.39	10.9	11.8	0.416	42	107
	2	36.9	15.8	3114	117^x	2.45	11.1^w	11.6	0.409	43	109
	3	32.8	15.5	3060	102	2.46	11.1^w	11.6	0.411	44	112
Test Average		35.0	15.7	3095							
System Average		30.0	16.4	3236							

^z 227 kg (500 lb) equivalent bales

^y slpm = standard l/min, scfm = standard ft^3/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 1st seed-cotton cleaning systems are shown in Table 3. The system average $PM_{2.5}$ emission factor was 0.0083 kg/bale (0.018 lb/bale). The test average $PM_{2.5}$ emission factors at each gin ranged from 0.0044 to 0.017 kg (0.010-0.038 lb) per bale and $PM_{2.5}$ emission rates ranged from 0.15 to 0.37 kg/h (0.32-0.82 lb/h). PM_{10} emissions data (ginning and emission rates and corresponding emission factors) for the 1st seed-cotton cleaning systems are shown in Table 4. The system average PM_{10} emission factor was 0.074 kg/bale (0.162 lb/bale). The test average emission factors ranged from 0.037 to 0.111 kg (0.081-0.245 lb) per bale and emission rates ranged from 0.65 to 3.30 kg/h (1.43-7.28 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the 1st seed-cotton cleaning systems are shown in Table 5. The system average total particulate emission factor was 0.101 kg/bale

(0.222 lb/bale). The test average emission factors ranged from 0.055 to 0.156 kg (0.120-0.344 lb) per bale. The test average total particulate emission rates ranged from 1.28 to 4.91 kg/h (2.83-10.82lb/h). The ratios of $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 8.3, 11.3, and 73.3%, respectively (ratios calculated using tables 3, 4, and 5 may vary slightly from those listed due to rounding).

The 1st seed-cotton cleaning system total particulate emission factor average for this project was about 61.6% of the EPA AP-42 published value for the No. 1 dryer and cleaner (EPA, 1996a, 1996b), which is an equivalent system to the 1st stage seed-cotton cleaning 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 1st seed-cotton cleaning system PM_{10} emission factor average for this project was 1.35 times the EPA AP-42 published value for the No. 1 dryer and cleaner. The test average PM_{10} emission factor range encompassed the AP-42 emission factor data range.

Table 3. $PM_{2.5}$ emissions data for the 1st stage seed-cotton cleaning systems.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.48	1.07	0.018	0.040
	2	0.29	0.64	0.019	0.042
	3	0.35	0.76	0.015	0.033
Test Average (n = 3)		0.37	0.82	0.017	0.038
B	1	0.13	0.29	0.011	0.025
	2	0.23	0.50	0.010	0.022
	3[y]	0.20	0.44	0.0080	0.018
Test Average (n = 2)		0.18	0.39	0.011	0.023
C	1	0.17	0.37	0.0072	0.016
	2	0.23	0.51	0.0091	0.020
	3[y]	0.16	0.34	0.0062	0.014
Test Average (n = 2)		0.20	0.44	0.0081	0.018
D	1	0.12	0.27	0.0038	0.008
	2	0.16	0.35	0.0046	0.010
	3	0.15	0.34	0.0049	0.011
Test Average (n = 3)		0.15	0.32	0.0044	0.010
E	1	0.21	0.47	0.0087	0.019
	2	0.23	0.52	0.0084	0.019
	3	0.19	0.43	0.0053	0.012
Test Average (n = 3)		0.21	0.47	0.0074	0.016
F	1	0.19	0.43	0.0046	0.010
	2	0.27	0.61	0.0061	0.013
	3	0.17	0.38	0.0034	0.0075
Test Average (n = 3)		0.21	0.47	0.0047	0.010
G	1	0.22	0.49	0.0063	0.014
	2	0.21	0.46	0.0057	0.012
	3	0.14	0.32	0.0044	0.010
Test Average (n = 3)		0.19	0.42	0.0054	0.012
System Average (n = 7)				0.0083	0.018

[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 1st stage seed-cotton cleaning systems.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1[y]	2.11	4.65	0.079	0.173
	2	1.56	3.44	0.104	0.230
	3	1.78	3.92	0.078	0.171
Test Average (n = 2)		1.67	3.68	0.091	0.200
B	1	0.47	1.04	0.041	0.091
	2[y]	1.37	3.03	0.060	0.132
	3	0.82	1.81	0.033	0.072
Test Average (n = 2)		0.65	1.43	0.037	0.081
C	1	2.21	4.88	0.093	0.206
	2	2.25	4.95	0.088	0.195
	3	1.97	4.34	0.078	0.172
Test Average (n = 3)		2.14	4.72	0.087	0.191
D	1	1.23	2.70	0.037	0.082
	2	1.41	3.10	0.040	0.089
	3	1.35	2.98	0.043	0.096
Test Average (n = 3)		1.33	2.92	0.040	0.089
E	1	2.69	5.99	0.110	0.243
	2	3.17	6.99	0.114	0.251
	3	4.04	8.90	0.110	0.242
Test Average (n = 3)		3.30	7.28	0.111	0.245
F	1	2.71	5.98	0.065	0.143
	2	3.28	7.23	0.073	0.160
	3	2.54	5.59	0.050	0.111
Test Average (n = 3)		2.84	6.27	0.063	0.138
G	1	3.09	6.80	0.087	0.192
	2[y]	2.95	6.50	0.080	0.176
	3[y]	1.72	3.79	0.052	0.116
Test Average (n = 1)		3.09	6.80	0.087	0.192
System Average (n = 7)				0.074	0.162

[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 1st stage seed-cotton cleaning systems.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	2.73	6.02	0.102	0.224
	2[y]	2.25	4.95	0.150	0.331
	3[y]	2.42	5.33	0.106	0.233
Test Average (n = 1)		2.73	6.02	0.102	0.224
B	1	0.67	1.47	0.058	0.128
	2	1.95	4.29	0.085	0.187
	3	1.23	2.72	0.049	0.108
Test Average (n = 3)		1.28	2.83	0.064	0.141
C	1	3.35	7.38	0.141	0.311
	2	3.24	7.13	0.127	0.281
	3[y]	3.13	6.89	0.124	0.273
Test Average (n = 2)		3.29	7.26	0.134	0.296
D	1	1.63	3.60	0.050	0.109
	2	2.06	4.53	0.059	0.130
	3	1.73	3.80	0.055	0.122
Test Average (n = 3)		1.80	3.98	0.055	0.120
E	1	4.04	8.91	0.165	0.364
	2	4.52	9.96	0.162	0.357
	3	5.19	11.45	0.141	0.311
Test Average (n = 3)		4.58	10.10	0.156	0.344
F	1	4.77	10.50	0.114	0.250
	2	5.64	12.43	0.125	0.275
	3	4.31	9.51	0.086	0.189
Test Average (n = 3)		4.91	10.82	0.108	0.238
G	1[y]	4.58	10.10	0.130	0.286
	2[y]	4.72	10.40	0.128	0.282
	3	2.79	6.14	0.085	0.187
Test Average (n = 1)		2.78	6.14	0.085	0.187
System Average (n = 7)				0.101	0.222

[z] 227 kg (500 lb) equivalent bales

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

Figure 16 shows an example of samples recovered from a typical 1st stage seed-cotton cleaning system test run. Often, there were cotton lint fibers, which have cross-sectional diameters much greater than 2.5 µm, in the cotton gin cyclone exhausts. Therefore, it was not unusual to find lint fiber in the > 10 µm wash from Method 201A. However, in the atypical sample shown in Fig. 17, lint fibers passed through the PM_{10} and $PM_{2.5}$ cyclones and were 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.

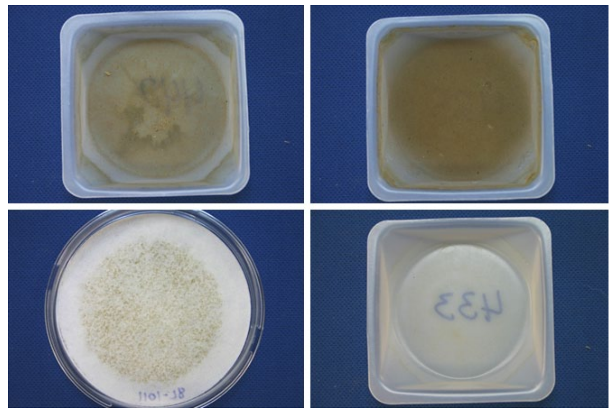

Figure 16. Typical EPA Method 201A filter and sampler head acetone washes from the 1st stage seed-cotton cleaning. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

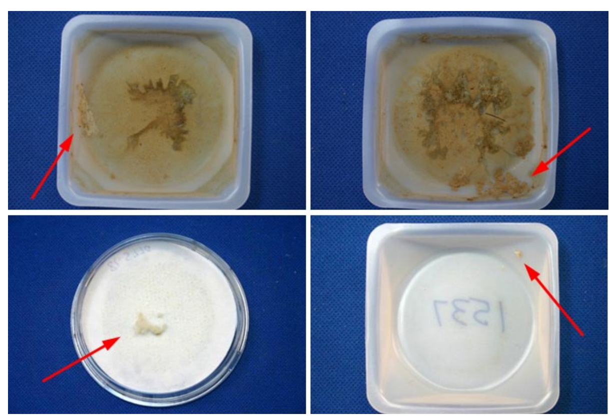

Figure 17. Atypical EPA Method 201A filter and sampler head acetone washes from the 1st stage seed-cotton cleaning with lint in all three washes and on the filter. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

SUMMARY

Seven cotton gins across the U.S. cotton belt were stack sampled using EPA Method 201A to fill the data gap that exists for $PM_{2.5}$ cotton gin emissions data. Each of the seven gins were equipped with 1st stage seed-cotton cleaning systems. 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 seven 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 1st seed-cotton cleaning system $PM_{2.5}$ emission factor based on the seven gins tested (19 total test runs) was 0.0083 kg/227-kg bale (0.018 lb/500-lb bale). The 1st seed-cotton cleaning system emission factors for PM_{10} and total particulate were 0.074 kg/bale (0.162lb/bale) and 0.101 kg/bale (0.222lb/bale), respectively. The gin average $PM_{2.5}$, PM_{10}, and total particulate emission rates ranged from 0.15 to 0.37 kg/h (0.32-0.82 lb/h), 0.65 to 3.30 kg/h (1.43-7.28 lb/h) and 1.28 to 4.91 kg/h (2.83-10.82 lb/h), respectively. System average PM_{10} emission factors were higher and system average total particulate emission factors were lower than those currently published in EPA AP-42. The ratios of $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 8.3, 11.3, and 73.3%, respectively. These data are the first published data to document $PM_{2.5}$ emissions from 1st stage seed-cotton cleaning systems at cotton gins.

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DISCLAIMER

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