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# ENGINEERING AND GINNING

## Master Trash System PM$_{2.5}$ Emission Factors and Rates for Cotton Gins: Method 201A Combination PM$_{10}$ and PM$_{2.5}$ Sizing Cyclones

Derek P. Whitelock, Michael D. Buser*, J. Clif Boykin, and Gregory A. Holt

### 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 was the development of PM$_{2.5}$ emission factors for cotton gin master trash systems based on the EPA-approved stack sampling methodology, Method 201A. The project plan included sampling seven cotton gins across the Cotton Belt. Five of the seven gins had master trash systems. In terms of capacity, the five gins were typical of the industry, averaging 37.1 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 master trash system PM$_{2.5}$ emission factor based on the five tests (13 total test runs) was 0.0042 kg/227-kg bale (0.0093 lb/500-lb bale). The master trash system average emission factors for PM$_{10}$ and total particulate were 0.036 kg/bale (0.080 lb/bale) and 0.143 kg/bale (0.314 lb/bale), respectively. The master trash system PM$_{2.5}$ emission rate from test averages ranged from 0.081 to 0.33 kg/h (0.18-0.73 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 master trash system PM$_{2.5}$ to total particulate, PM$_{2.5}$ to PM$_{10}$, and PM$_{10}$ to total particulate were 2.9, 11.5, and 25.5%, 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-mm (PM$_{2.5}$) aerodynamic equivalent diameter (CFR, 2006). The cotton industry's primary concern with this standard was that there were no published cotton gin PM$_{2.5}$ emissions data. Cotton ginners' associations across the Cotton Belt, including the National, Texas, Southern, Southeastern, and California associations, agreed that there was an urgent need to collect PM$_{2.5}$ cotton gin emissions data to address the implementation of the PM$_{2.5}$ standards. Working with cotton ginning associations across the country and state and federal regulatory agencies, Oklahoma State University and USDA-Agricultural Research Service (ARS) researchers developed a proposal and sampling plan that was initiated in 2008 to address this need for additional data. This report is part of a series that details cotton gin emissions measured by stack sampling. Each manuscript in the series addresses a specific cotton ginning system. The systems covered in the series include: unloading, first-stage seed cotton cleaning, second-stage seed cotton cleaning, third-stage seed cotton cleaning, overflow, first-stage lint cleaning, second-stage lint cleaning, combined lint cleaning, cyclone robber, first-stage mote, second-stage mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser, and master trash. This report focuses on PM$_{2.5}$ emissions from master trash systems.

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D.P. Whitelock, USDA-ARS Southwestern Cotton Ginning Research Laboratory, Mesilla Park, NM 88047; M.D. Buser*, Oklahoma State University, Stillwater, OK 74078; J.C. Boykin, USDA-ARS Cotton Ginning Research Unit, Stoneville, MS 38776; and G.A. Holt, USDA-ARS Cotton Production and Processing Research Unit, Lubbock, TX 79401
*Corresponding author: buser@okstate.edu

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 master trash fan was 0.034 kg (0.074 lb) per 217-kg (480-lb) equivalent bale with a range of 0.017 to 0.051 kg (0.038-0.11 lb) per bale. The AP-42 average total particulate emission factor was 0.24 kg (0.54 lb) per bale with a range of 0.060 to 0.57 kg (0.13-1.3 lb) per bale. These $PM_{10}$ and total factors were based on two and four 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 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 instead 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).

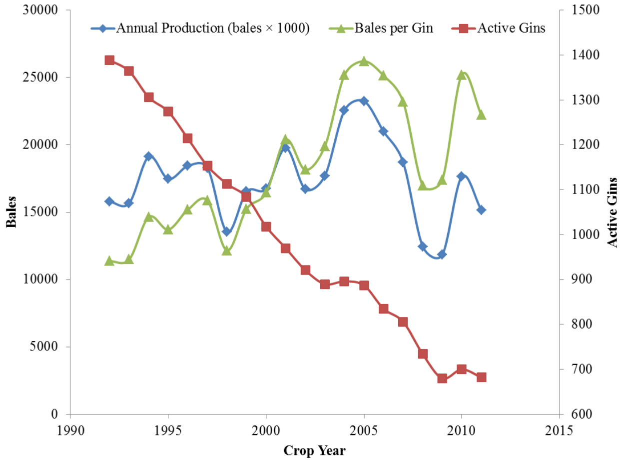

**Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).**

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 it into dense bales for efficient transport. Gin systems produce by-products or trash, such as rocks, soil, sticks, hulls, leaf material, and short or tangled immature fiber (motes), as a result of processing the seed cotton 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.

Many of the gin systems produce by-product or trash as a result of processing the cotton, lint, or further processing a by-product. In each case, the stream of trash must be removed from the machinery and handled by trash systems (Fig. 3). Typically, all trash at gins is consolidated into one storage area for subsequent removal. In some cases, the particulate abatement cyclones for different gin systems are located over a trash hopper and thus a main trash system is not necessary. In many other cases, a master trash system will pull trash from systems throughout the gin – pre-cleaning systems trash conveyors, gin stands trash conveyor, and the main trash conveyor often located under the unloading system, seed cotton cleaning system, overflow system, and other systems particulate abatement cyclones. The trash is pneumatically conveyed to one or two master trash cyclones located over either a storage hopper or a trash pile. The material handled by the master trash cyclones typically includes any and all types of trash encountered by the gin systems (rocks, soil, sticks, hulls, leaf material, and lint) and these cyclones are often quite heavily loaded. A photograph of the material typically collected by the master trash system is shown in Fig. 4.

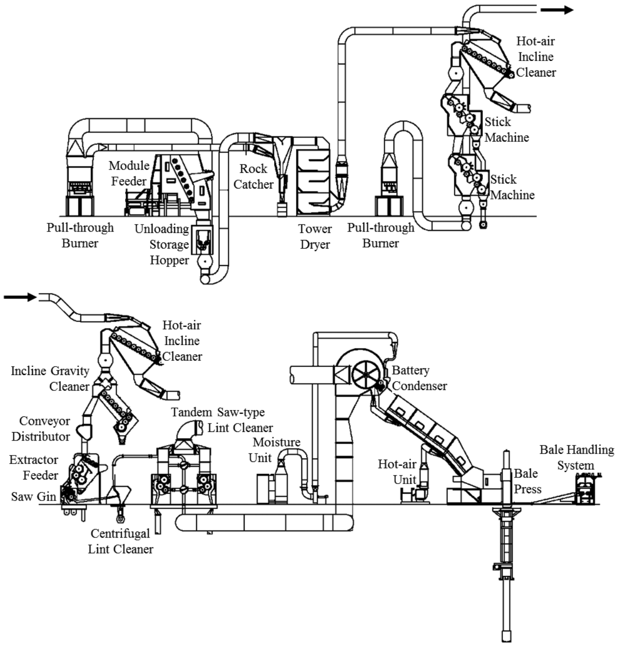

**Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).**

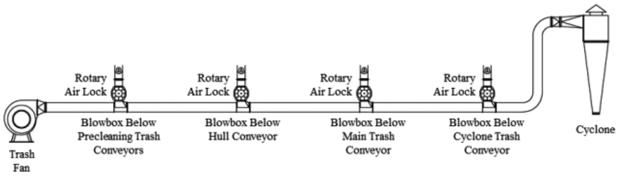

**Figure 3. Typical cotton gin master trash system layout (Courtesy Lummus Corporation, Savannah, GA).**

**Figure 4. Photograph of typical trash captured by the master trash 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 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).

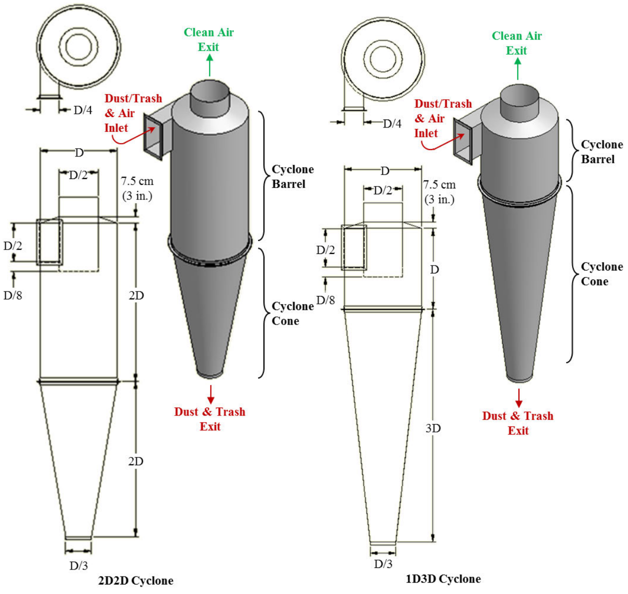

**Figure 5. 2D2D and 1D3D cyclone schematics.**

The objective of this study is the development of PM$_{2.5}$ emission factors for cotton gin master trash 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 bBelt. 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 master trash 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 fraction size 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.

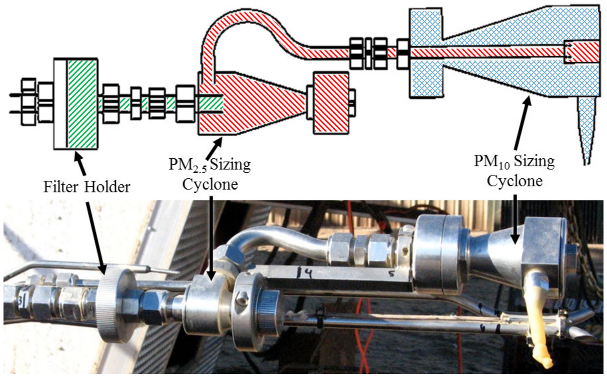

**Figure 6. EPA Method 201A PM$_{10}$ and PM$_{2.5}$ sizing cyclones and in-stack filter holder schematic (CFR, 2010) and photograph (🟩 ≤ 2.5 µm, 🟥 10 to 2.5 µm, 🟦 > 10 µm).**

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.

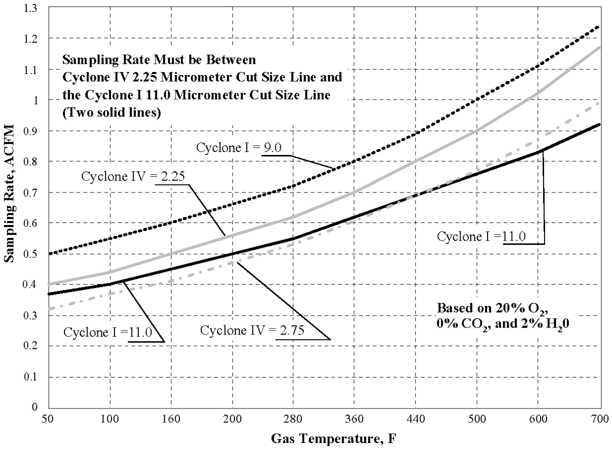

**Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = $PM_{10}$ sizing cyclone and Cyclone IV = $PM_{2.5}$ sizing cyclone (Gas temperatures for the master trash systems tested ranged from 27 to 41°C [80-105°F]).**

Only one stack from each master trash 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 prelabeled 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 of the 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.

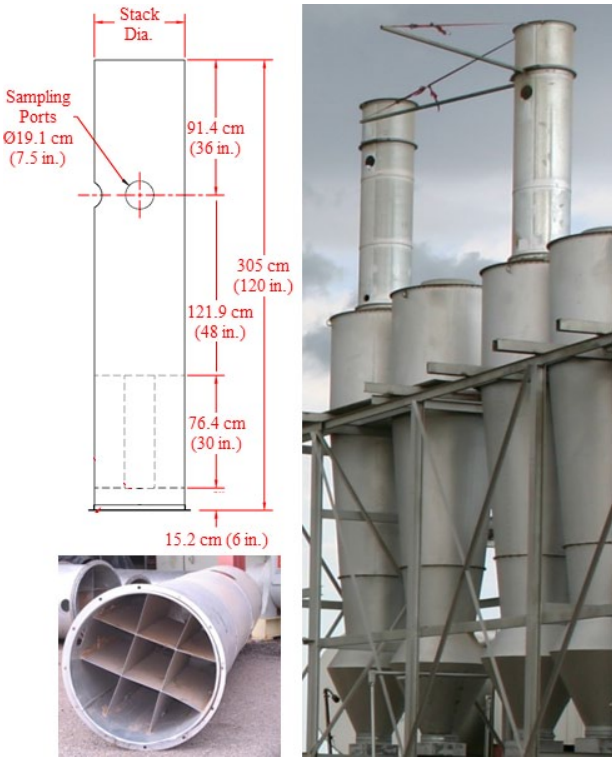

**Figure 8. Schematic and photographs of stack extensions with sampling ports and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).**

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 (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).

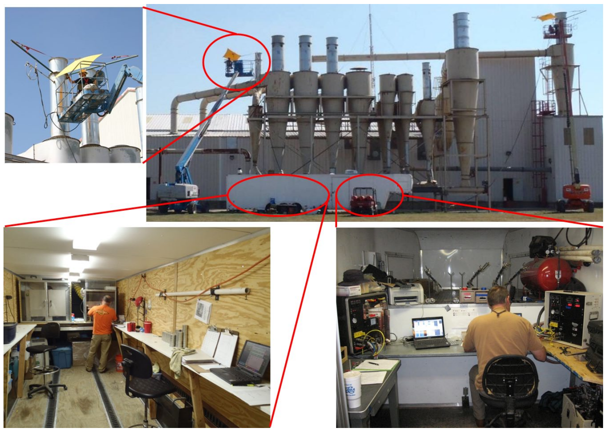

Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

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.

Five of the seven gins had master trash systems. The master trash systems sampled were typical for the industry, but varied among gins. The master trash systems at gins B, E, F, and G handled all the material generated from processing the cotton through the gin that was considered trash. This material was picked up at individual machines within the gin plant and/or at the main trash auger under the cyclones outside of the gin and pneumatically conveyed to one or more cyclones above a trash pile or trash hopper. The master trash system at gin D did not handle trash from all of the gin systems, but consolidated and conveyed material from the unloading systems, two 2nd stage seed-cotton cleaners, four feeder and gin stand systems, and four centrifugal lint cleaners before the 1st stage lint cleaning systems.

Four of the five master trash systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among those gins (Table 1 and Fig. 10). The system airstream for gins B and G was exhausted through a single cyclone. Gins D and F split the system exhaust flows between two cyclones in a dual configuration (side-by-side as opposed to one-behind-another). Inlets on the master trash cyclones for gins B, D, F, and G were 2D2D type. Expansion chambers were present on master trash cyclones at gins B and D. The cyclones on the master trash systems for Gins F and G 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 cyclone on the master trash system for gin E was not a 1D3D cyclone (Fig. 10). This cyclone had proportional dimensions of about ½D2D with a square inlet that measured approximately ¼D on each side and had a standard cone with a narrow trash exit. Although the gin E master trash system was not equipped with a 1D3D cyclone, the system was sampled and included in the emissions analyses with the other four master trash systems that were equipped with 1D3D cyclones.

Figure 10. 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 2D2D inlet and expansion chamber on the cone; 1D3D cyclone with 2D2D inlet and standard cone; ½D2D cyclone with a square inlet measuring about ¼D on a side.

**Table 1. Abatement device configuration[z] for master trash systems tested.**

| Gin | Cyclone Type | Inlet Design[y] | Systems per Gin | Cyclones per Gin | Configuration | Cone Design | Trash exits to[x] |
|---|---|---|---|---|---|---|---|
| B | 1D3D | 2D2D | 1 | 1 | single | expansion chamber | auger |
| D | 1D3D | 2D2D | 1 | 2 | dual | expansion chamber | hopper |
| E | ½D2D | square | 1 | 1 | single | standard | auger |
| F | 1D3D | 2D2D | 1 | 2 | dual | standard | auger |
| G | 1D3D | 2D2D | 1 | 1 | single | standard | hopper |

[z] Figures 5 and 10

[y] Square inlet design had cross-section approximately one-fourth the cyclone diameter on a side

[x] Systems to remove material from cyclone trash exits: hopper = large storage container directly under cyclone trash exit; auger = enclosed, screw-type conveyor

## RESULTS

Table 2 shows the test parameters for each Method 201A test run for the master trash systems sampled at the five gins. The system average ginning rate was 37.1 bales/h and the test average ginning rates at each gin ranged from 28.4 to 46.7 bales/h (based on 227-kg [500-lb] equivalent bales). The 1D3D cyclones were all operated with inlet velocities within design criteria, 16.3 ± 2 m/s (3200 ± 400 fpm), except the second test run for gin D was outside the design range due to limitations in available system adjustments. The inlet velocity for the ½D2D cyclone at gin E ranged from 10.7 to 10.9 m/s (2,113-2,155 fpm) for the test runs.

**Table 2. Cotton gin production data and stack sampling performance metrics for the master trash 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 |
| B | 1 | 26.5 | 17.0 | 3355 | 103 | 2.58 | 11.4[x] | 11.0 | 0.389 | 41 | 105 |
| | 2 | 31.1 | 17.1 | 3360 | 90 | 2.48 | 11.2[x] | 11.2 | 0.397 | 37 | 99 |
| | 3 | 27.5 | 16.8 | 3305 | 99 | 2.22[x] | 10.5 | 12.2 | 0.432 | 36 | 97 |
| Test Average | | 28.4 | 17.0 | 3340 | | | | | | | |
| D | 1 | 37.2 | 14.3 | 2824 | 100 | 2.42 | 11.1[x] | 11.1 | 0.393 | 30 | 86 |
| | 2 | 37.8 | 14.1 | 2769 | 103 | 2.40 | 11.0 | 11.2 | 0.397 | 31 | 87 |
| | 3 | 35.6 | 14.5 | 2860 | 97 | 2.49 | 11.3[x] | 10.9 | 0.384 | 30 | 86 |
| Test Average | | 36.9 | 14.3 | 2817 | | | | | | | |
| E | 1 | 37.0 | 10.9 | 2155 | 98 | 2.44 | 11.1[x] | 11.0 | 0.387 | 27 | 81 |
| | 2 | 33.7 | 10.7 | 2113 | 102 | 2.40 | 11.0 | 11.2 | 0.394 | 28 | 83 |
| | 3 | 34.3 | 10.8 | 2122 | 103 | 2.37 | 10.9 | 11.4 | 0.401 | 29 | 85 |
| Test Average | | 35.0 | 10.8 | 2130 | | | | | | | |
| F | 1 | 39.8 | 14.4 | 2843 | 103 | 2.55 | 11.2[x] | 12.5 | 0.442 | 37 | 99 |
| | 2 | 49.4 | 15.0 | 2947 | 91 | 2.81[x] | 11.9[x] | 10.6 | 0.374 | 38 | 101 |
| | 3 | 50.8 | 14.4 | 2831 | 103 | 2.57 | 11.3[x] | 11.5 | 0.404 | 39 | 103 |
| Test Average | | 46.7 | 14.6 | 2874 | | | | | | | |
| G | 1 | 38.1 | 15.4 | 3030 | 107 | 2.60 | 11.6[x] | 10.3 | 0.365 | 27 | 80 |
| | 2 | 37.3 | 15.4 | 3037 | 92 | 2.74 | 11.9[x] | 10.0 | 0.352 | 28 | 82 |
| | 3 | 40.0 | 15.1 | 2965 | 99 | 2.42 | 11.1[x] | 11.0 | 0.388 | 27 | 80 |
| Test Average | | 38.5 | 15.3 | 3011 | | | | | | | |
| Project Average | | 37.1 | 14.4 | 2834 | | | | | | | |

[z] 227 kg (500 lb) equivalent bales

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

[x] 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). To use the method to also obtain total filterable particulate, sampling must be within 90 to 110% of isokinetic flow All test runs met this criteria and were included in the total particulate test averages. The $PM_{2.5}$ aerodynamic cut size must fall within EPA defined ranges (2.50 ± 0.25 mm) for valid $PM_{2.5}$ test runs. $PM_{2.5}$ cut size criteria were not met in the third test run for gin B or the second run for gin F, thus the data associated with these runs were omitted from the $PM_{2.5}$ test averages. The $PM_{10}$ aerodynamic cut size must fall within EPA defined ranges (10.0 ± 1.0 mm) for valid $PM_{10}$ test runs. The $PM_{10}$ cut size criteria was only met in the third test run for gin B, the second test run for gin D, and the last two test runs for gin E; thus these were the only data used for the $PM_{10}$ test averages.

Sampling rates ranged from 10.0 to 12.5 standard l/min (0.352 to 0.442 standard $ft^3$/min) (Table 2). The stack gas temperatures ranged from 27 to 41˚C (80-105˚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.

$PM_{2.5}$ emissions data (ginning and emission rates and corresponding emission factors) for the master trash systems are shown in Table 3. The system average $PM_{2.5}$ emission factor was 0.0042 kg/bale (0.0093 lb/bale). The test average emission factors at each gin ranged from 0.0027 to 0.0072 kg (0.0059-0.016 lb) per bale and $PM_{2.5}$ emission rates ranged from 0.081 to 0.33 kg/h (0.18-0.73 lb/h). $PM_{10}$ emissions data (ginning and emission rates and corresponding emission factors) for the master trash systems are shown in Table 4. The system average $PM_{10}$ emission factor was 0.036 kg/bale (0.080 lb/bale). The test average emission factors ranged from 0.026 to 0.044 kg (0.057-0.098 lb) per bale and emission rates ranged from 0.71 to 1.67 kg/h (1.56-3.69 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the master trash systems are shown in Table 5. The system average total particulate emission factor was 0.143 kg/bale (0.314 lb/bale). The test average emission factors ranged from 0.066 to 0.221 kg (0.145-0.486 lb) per bale. The test average total particulate emission rates ranged from 2.14 to 7.84 kg/h (4.73-17.29 lb/h). The ratios of $PM_{2.5}$ to total particulate, $PM_{2.5}$ to $PM_{10}$, and $PM_{10}$ to total particulate were 2.9, 11.5, and 25.5%, respectively (ratios calculated using tables 3, 4, and 5 may vary slightly from those listed due to rounding).

**Table 3. $PM_{2.5}$ emissions data for the master trash systems.**

| Gin | Test Run | Emission Rate, | | Emission Factor, | |
|---|---|---|---|---|---|
| | | kg/h | lb/h | kg/bale[z] | lb/bale[z] |
| B | 1 | 0.050 | 0.11 | 0.0019 | 0.0042 |
| | 2 | 0.11 | 0.25 | 0.0036 | 0.0080 |
| | 3[y] | 0.047 | 0.10 | 0.0017 | 0.0038 |
| Test Average (n=2) | | 0.081 | 0.18 | 0.0028 | 0.0061 |
| D | 1 | 0.15 | 0.33 | 0.0040 | 0.0089 |
| | 2 | 0.21 | 0.46 | 0.0056 | 0.012 |
| | 3 | 0.26 | 0.58 | 0.0074 | 0.016 |
| Test Average (n=3) | | 0.21 | 0.46 | 0.0057 | 0.012 |
| E | 1 | 0.12 | 0.27 | 0.0033 | 0.0072 |
| | 2 | 0.053 | 0.12 | 0.0016 | 0.0034 |
| | 3 | 0.11 | 0.24 | 0.0031 | 0.0069 |
| Test Average (n=3) | | 0.094 | 0.21 | 0.0027 | 0.0059 |
| F | 1 | 0.25 | 0.56 | 0.0064 | 0.014 |
| | 2[y] | 0.59 | 1.29 | 0.012 | 0.026 |
| | 3 | 0.41 | 0.90 | 0.0080 | 0.018 |
| Test Average (n=2) | | 0.33 | 0.73 | 0.0072 | 0.016 |
| G | 1 | 0.058 | 0.13 | 0.0015 | 0.0034 |
| | 2 | 0.15 | 0.34 | 0.0041 | 0.0091 |
| | 3 | 0.10 | 0.23 | 0.0026 | 0.0057 |
| Test Average (n=3) | | 0.11 | 0.23 | 0.0028 | 0.0061 |
| Project Average (n=5) | | | | 0.0042 | 0.0093 |

[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

The master trash system total particulate emission factor average for this project was about 58.2% of the EPA AP-42 published value for the master trash fan (EPA, 1996a, 1996b). The range of test average total particulate emission factors determined for this project fell within the range of AP-42 emission factor data. The master trash system $PM_{10}$ emission factor average for this project was 1.08 times the EPA AP-42 published value for the master trash fan. The test average $PM_{10}$ emission factor range also fell within the AP-42 emission factor data range.

**Table 4. $PM_{10}$ emissions data for the master trash systems.**

| Gin | Test Run | Emission Rate, | | Emission Factor, | |
|---|---|---|---|---|---|
| | | kg/h | lb/h | kg/bale$^z$ | lb/bale$^z$ |
| B | $1^y$ | 0.95 | 2.09 | 0.036 | 0.079 |
| | $2^y$ | 1.15 | 2.54 | 0.037 | 0.082 |
| | 3 | 0.71 | 1.56 | 0.026 | 0.057 |
| Test Average (n=1) | | 0.71 | 1.56 | 0.026 | 0.057 |
| D | $1^y$ | 1.27 | 2.81 | 0.034 | 0.075 |
| | 2 | 1.67 | 3.69 | 0.044 | 0.098 |
| | $3^y$ | 2.01 | 4.43 | 0.056 | 0.124 |
| Test Average (n=1) | | 1.67 | 3.69 | 0.044 | 0.098 |
| E | $1^y$ | 3.56 | 7.85 | 0.096 | 0.212 |
| | 2 | 1.12 | 2.47 | 0.033 | 0.073 |
| | 3 | 1.54 | 3.40 | 0.045 | 0.099 |
| Test Average (n=2) | | 1.33 | 2.93 | 0.039 | 0.086 |
| F | $1^y$ | 2.65 | 5.84 | 0.066 | 0.147 |
| | $2^y$ | 3.94 | 8.69 | 0.080 | 0.176 |
| | $3^y$ | 2.87 | 6.33 | 0.057 | 0.125 |
| Test Average (n=0) | | | | | |
| G | $1^y$ | 1.57 | 3.45 | 0.041 | 0.091 |
| | $2^y$ | 3.94 | 8.68 | 0.106 | 0.233 |
| | $3^y$ | 3.13 | 6.90 | 0.078 | 0.173 |
| Test Average (n=0) | | | | | |
| Project Average (n=3) | | | | 0.036 | 0.080 |

$^z$ 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

Figure 11 shows an example of samples recovered from a typical master trash system test run. Often, there were cotton lint fibers, which have cross-sectional diameters much greater than 2.5 mm, in the cotton gin cyclone exhausts. Therefore, it was not unusual to find lint fiber in the > 10 µm wash from Method 201A. However, in the atypical sample shown in Figure 12, lint fibers passed through the $PM_{10}$ and $PM_{2.5}$ cyclones and collected in the 10 to 2.5 µm and ≤ 2.5 mm 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.

**Table 5. Total particulate emissions data for the master trash systems.**

| Gin | Test Run | Emission Rate, | | Emission Factor, | |
|---|---|---|---|---|---|
| | | kg/h | lb/h | kg/bale$^z$ | lb/bale$^z$ |
| B | 1 | 1.77 | 3.90 | 0.067 | 0.147 |
| | 2 | 2.94 | 6.47 | 0.094 | 0.208 |
| | 3 | 1.73 | 3.82 | 0.063 | 0.139 |
| Test Average (n=3) | | 2.14 | 4.73 | 0.075 | 0.165 |
| D | 1 | 1.94 | 4.28 | 0.052 | 0.115 |
| | 2 | 2.46 | 5.41 | 0.065 | 0.143 |
| | 3 | 2.87 | 6.33 | 0.081 | 0.178 |
| Test Average (n=3) | | 2.42 | 5.34 | 0.066 | 0.145 |
| E | 1 | 12.80 | 28.23 | 0.346 | 0.764 |
| | 2 | 5.10 | 11.23 | 0.151 | 0.334 |
| | 3 | 5.63 | 12.41 | 0.164 | 0.362 |
| Test Average (n=3) | | 7.84 | 17.29 | 0.221 | 0.486 |
| F | 1 | 6.53 | 14.39 | 0.164 | 0.361 |
| | 2 | 9.46 | 20.86 | 0.192 | 0.423 |
| | 3 | 5.76 | 12.71 | 0.114 | 0.250 |
| Test Average (n=3) | | 7.25 | 15.99 | 0.156 | 0.345 |
| G | 1 | 5.28 | 11.63 | 0.138 | 0.305 |
| | 2 | 9.28 | 20.46 | 0.249 | 0.548 |
| | 3 | 7.91 | 17.44 | 0.198 | 0.436 |
| Test Average (n=3) | | 7.49 | 16.51 | 0.195 | 0.430 |
| Project Average (n=5) | | | | 0.143 | 0.314 |

$^z$ 227 kg (500 lb) equivalent bales

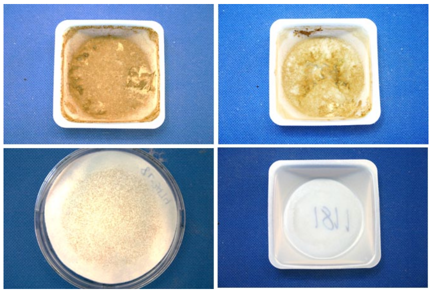

Figure 11. Typical EPA Method 201A filter and sampler head acetone washes from the master trash system. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

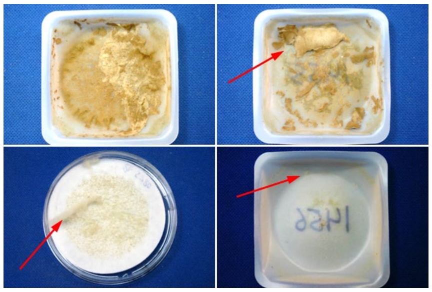

Figure 12. Atypical EPA Method 201A filter and sampler head acetone washes from the master trash syestem with lint fiber in the 10 to 2.5 µm and 2.5 µm washes and on the filter. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

## 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. Five of the seven gins had master trash 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, except for one that was equipped with a ½D2D cyclone. In terms of capacity, the five gins were typical of the industry, averaging 37.1 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 master trash system $PM_{2.5}$ emission factor based on the five gins tested (13 total test runs) was 0.0042 kg/227-kg bale (0.0093 lb/500-lb bale). The master trash system emission factors for $PM_{10}$ and total particulate were 0.036 kg/bale (0.080 lb/bale) and 0.143 kg/bale (0.314 lb/bale), respectively. The gin test average $PM_{2.5}$, $PM_{10}$ and total particulate emission rates ranged from 0.081 to 0.33 kg/h (0.18-0.73 lb/h), 0.71 to 1.67 kg/h (1.56-3.69 lb/h) and 2.14 to 7.84 kg/h (4.73-17.29 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 master trash system $PM_{2.5}$ to total particulate, $PM_{2.5}$ to $PM_{10}$, and $PM_{10}$ to total particulate were 2.9, 11.5, and 25.5%, respectively. These data are the first published data to document $PM_{2.5}$ emissions from master trash systems at cotton gins.

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## DISCLAIMER

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