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# ENGINEERING AND GINNING

## Mote Cleaner 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 mote cleaner systems based on the EPA-approved stack sampling methodology, Method 201A. The project plan included sampling seven cotton gins across the Cotton Belt. This information is repeated in the body of the text and this detail can be left out in the abstract shortening it some. 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 cleaner system $PM_{2.5}$ and total particulate emission factors for the stand-alone mote cleaner system were 0.0036 kg/227-kg bale (0.0079 lb/500-lb bale) and 0.065 kg/bale (0.14 lb/bale). The average total particulate emission factor for the stand-alone mote cleaner system was lower than those currently published in EPA AP-42 for similar systems. The ratio of mote cleaner system $PM_{2.5}$ to total particulate was 5.5%. Average measured $PM_{2.5}$ emission factors for the mote cleaner system combined with the module feeder dust system was 0.022 kg/bale (0.050 lb/bale).**

In 2006, the U.S. Environmental Protection Agency (EPA) finalized a more stringent standard for particulate matter emmisions for particles with a 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 cleaner 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

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no $PM_{2.5}$ emission factors. There are no 1996 EPA AP-42 average emission factors for mote cleaner systems. The mote cleaner system would be similar to the combined factors for the mote fan and the mote trash fan listed in AP-42. The AP-42 average $PM_{10}$ emission factor for the mote fan was 0.060 kg (0.13 lb) per 217-kg (480-lb) bale with a range of 0.023 to 0.14 kg (0.050-0.30 lb) per bale. The AP-42 $PM_{10}$ emission factor for the mote trash fan was 0.0095 kg (0.021 lb) per bale and ranged from 0.0021 to 0.018 kg (0.0046-0.040 lb) per bale. These $PM_{10}$ factors were based on six and three 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 mote fan was 0.13 kg (0.28 lb) per bale with a range of 0.045 to 0.47 kg (0.099-1.0 lb) per bale. This average and range was based on nine tests. The total particulate emission factor for the mote trash fan was 0.035 kg (0.077 lb) per bale, and ranged from 0.025 to 0.051 kg (0.055-0.11 lb) per bale, based on three tests. These total factors 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 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, they have 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 Cotton Belt (Valco et al., 2003, 2006, 2009, 2012).

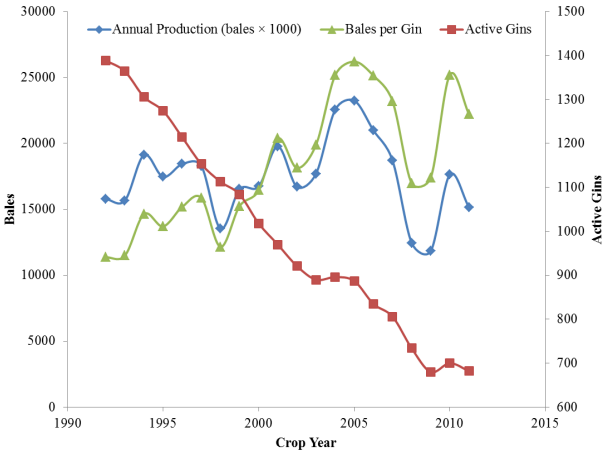


**Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).**

Typical cotton gin processing systems include: an 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 vary from gin to gin. Each of these systems serves a unique function with the ultimate goal of producing 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. These 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.

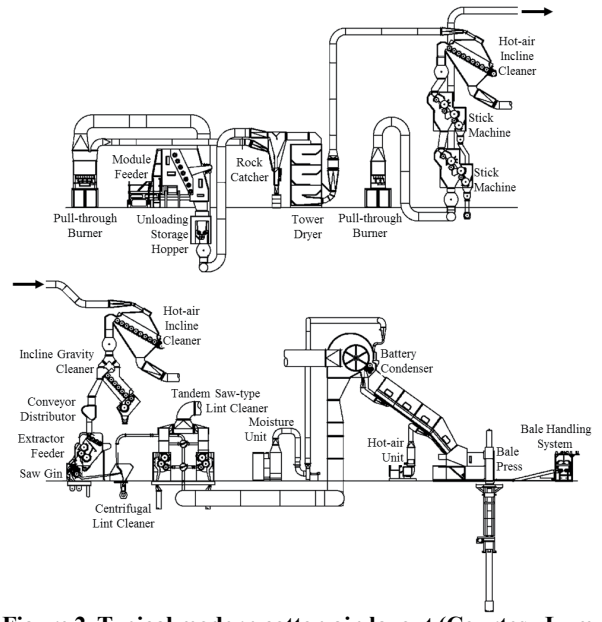


**Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).**

Material captured by cyclones that handle airstreams laden with greater amounts of lint (battery condenser, lint cleaning, and mote system cyclones), referred to as "motes", has considerable value, especially when cleaned in a device similar to a seed cotton cleaning machine; the mote cleaner. In mote cleaner systems (Fig. 3) the material is pneumatically conveyed from the trash exit of the cyclones to a screened separator where the motes are separated from the conveying airstream and dropped into the mote cleaner. The airstream from the screened separator continues through a centrifugal fan to one or two particulate abatement cyclones. A branch of the pneumatic system between the separator and fan is often utilized to pick up, by suction, the mote trash from the mote cleaner trash exit. The material handled by the mote cleaner system cyclones typically includes small leaf trash, soil, and some lint fibers (Fig. 4).

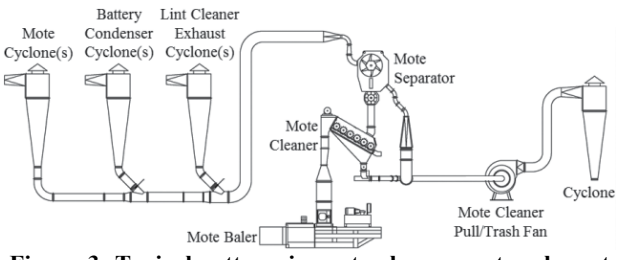


**Figure 3. Typical cotton gin mote cleaner system layout (Courtesy Lummus Corporation, Savannah, GA).**

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

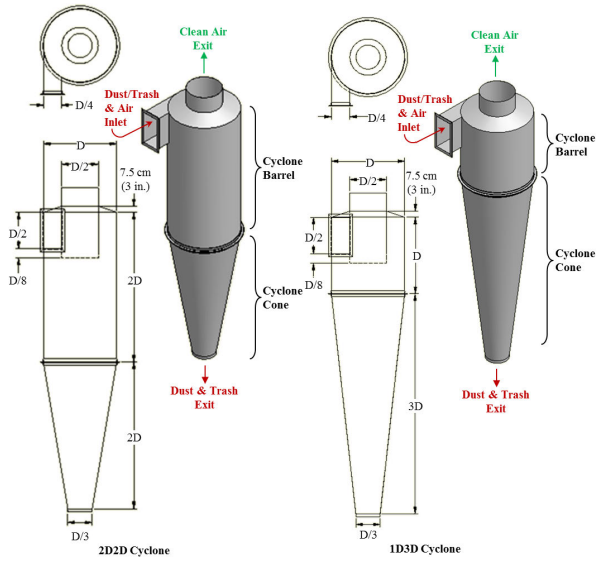


**Figure 5. 2D2D and 1D3D cyclone schematics.**

The objective of this study was the development of $PM_{2.5}$ emission factors for cotton gin mote cleaner 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 cleaner 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.

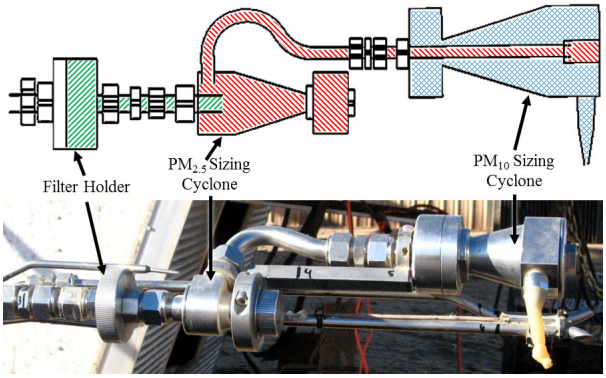


**Figure 6. EPA Method 201A $PM_{10}$ and $PM_{2.5}$ sizing cyclones and in-stack filter holder schematic (CFR, 2010) and photograph (≤ 2.5 µm, 10 to 2.5 µm, > 10 µm).**

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.

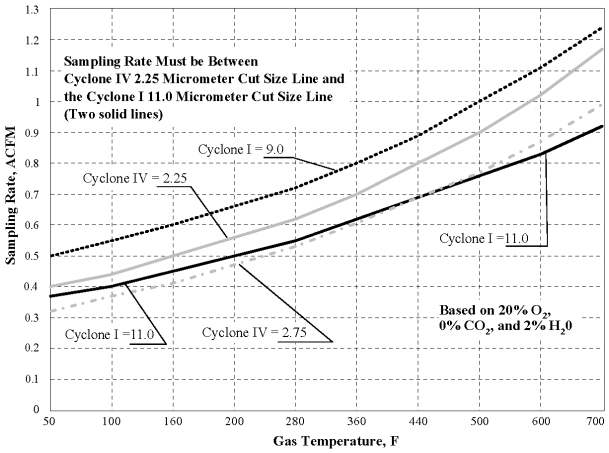


**Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = $PM_{10}$ sizing cyclone and Cyclone IV = $PM_{2.5}$ sizing cyclone (Gas temperatures for the mote cleaner systems tested ranged from 28 to 32˚C [83-89˚F]).**

Only one stack from each mote cleaner 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.

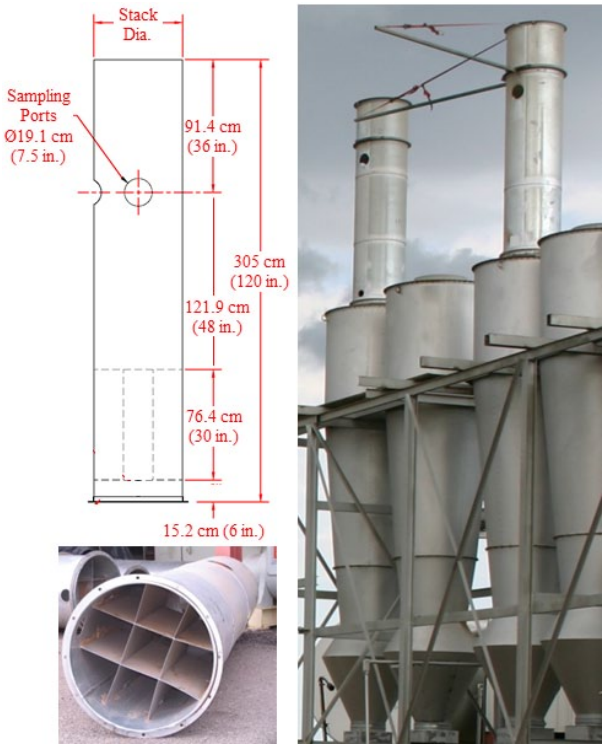


**Figure 8. Schematic and photographs of stack extensions with sampling ports and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).**

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 ASAE Standard S582 (ASABE, 2005).

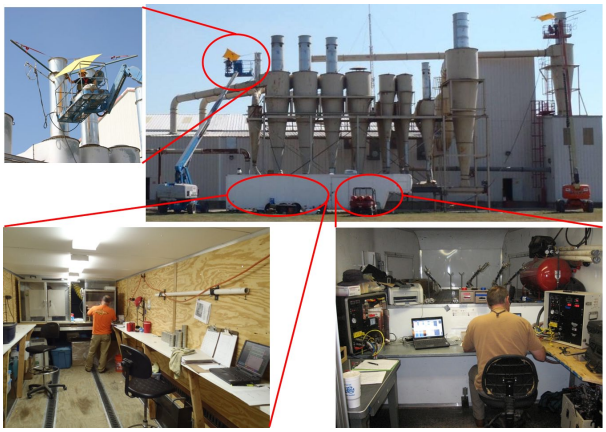

**Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.**

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

Two of the seven gins had mote cleaner systems. The mote cleaner systems sampled were typical for the industry. At gin G (Fig. 10), the motes were pneumatically conveyed from the trash exit of the lint handling cyclones (mote, lint cleaning, and battery condenser systems) to the mote cleaner. At the mote cleaner, the motes were separated from the conveying airstream by a screened separator and dropped into the cleaner. The airstream from the screened separator continued through a centrifugal fan to a cyclone. The mote trash was picked up from the trash exit of the mote cleaner and combined with the exhaust airstream from the screened separator prior to the inlet of the fan. The mote cleaner system at gin F was essentially the same, except a conveying airstream from a system that captured dust generated at the module feeder (module feeder dust system) was combined with the exhaust airstream before the fan (Fig. 11). The addition of the module feeder dust system could significantly influence the particulate matter test results for the gin F mote cleaner system; therefore, no system averages were calculated.

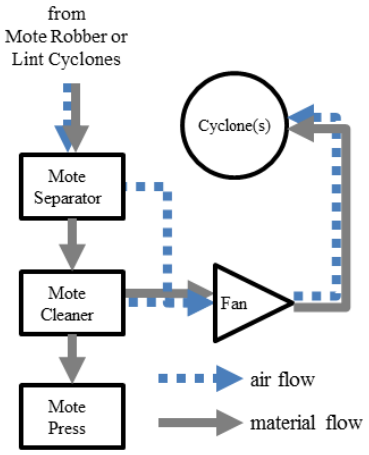


**Figure 10. Schematic of mote cleaner system (gin G).**

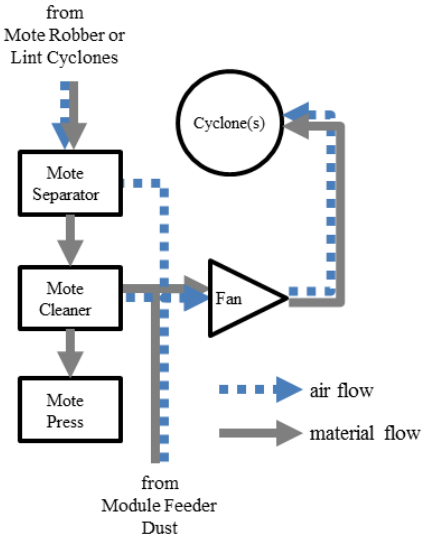


**Figure 11. Schematic of mote cleaner system combined with module feeder dust system (gin F).**

The mote cleaner systems sampled at both gins F and G utilized single 1D3D cyclones to control emissions (Table 1 and Figures 5 and 12). The mote cleaner cyclone design for both systems included a 2D2D inlet and standard cone. These cyclone characteristics, if properly designed and maintained, are recommended for controlling cotton gin emissions (Whitelock et al., 2009).

**Figure 12. Cyclone design for the tested systems: 1D3D cyclone with 2D2D inlet and standard cone.**

## RESULTS

Table 2 shows the test parameters for each Method 201A test run for the mote cleaner systems sampled. The system average ginning rate for the gin F mote cleaning and module feeder dust system was 47.6 bales/h and the test average ginning rates ranged from 46.0 to 50.0 bales/h (based on 227-kg [500-lb] equivalent bales). The system average ginning rate for the gin G mote cleaning was 35.1 bales/h and test average ginning rates ranged from 34.2 to 36.8 bales/h. The 1D3D cyclone at gin F was operated with inlet velocities within design criteria, 16.3 ± 2 m/s (3200 ± 400 fpm). The cyclone at gin G was operated 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 Method 201A to obtain total filterable particulate, sampling must be within 90 to 110% of isokinetic flow. This criterion was only met in the first and third test runs at gin G; thus the data associated with all other test 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 was met in all tests. 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 was not met in any of the tests; thus the data could not be used to determine test average $PM_{10}$ emission factors.

Sampling rates ranged from 10.3 to 10.9 standard l/min (0.365-0.383 standard $ft^3$/min) for the gin F system, and10.7 to 11.1 standard l/min (0.379-0.392 standard $ft^3$/min) for the gin G system (Table 2). The stack gas temperatures ranged from 28 to 32˚C for the gin F system and 30 to 31˚C for the gin G system. The sampling method documentation (CFR, 2010) warns that the acceptable gas sampling rate range is limited at the stack gas temperatures encountered during this project's testing, as indicated by the narrow difference between the solid lines in Figure 7 for the temperatures listed above. These stack gas characteristics justified targeting the $PM_{2.5}$ cut size criteria and treating the $PM_{10}$ cut size criteria as secondary.

**Table 1. Abatement device configuration[z] for mote cleaner systems tested.**

| Gin | Cyclone Type | Inlet Design | Systems per Gin | Cyclones per Gin | Configuration | Cone Design | Trash exits to[y] |
|---|---|---|---|---|---|---|---|
| F | 1D3D | 2D2D | 1 | 1 | single | standard | auger |
| G | 1D3D | 2D2D | 1 | 1 | single | standard | auger |

[z] Figures 5 and 12

[y] Systems to remove material from cyclone trash exits: auger = enclosed, screw-type conveyor

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

| Gin | Test Run | Ginning Rate bales/h[z] | Cyclone Inlet Velocity | | Isokinetic Sampling % | Aerodynamic Cut Size $D_{50}$ | | Sampling Rate | | Stack Temperature | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | m/s | fpm | | $PM_{2.5}$ µm | $PM_{10}$ µm | slpm | scfm | °C | °F |
| F[x] | 1 | 46.8 | 16.1 | 3177 | 83[w] | 2.75 | 11.8[v] | 10.3 | 0.365 | 28 | 83 |
| | 2 | 46.0 | 16.7 | 3279 | 81[w] | 2.74 | 11.8[v] | 10.5 | 0.370 | 30 | 86 |
| | 3 | 50.0 | 16.5 | 3247 | 85[w] | 2.64 | 11.5[v] | 10.9 | 0.383 | 32 | 89 |
| Test Average | | 47.6 | 16.4 | 3234 | | | | | | | |
| G | 1 | 34.3 | 18.8 | 3703 | 91 | 2.53 | 11.4[v] | 10.7 | 0.379 | 31 | 87 |
| | 2 | 34.2 | 20.1 | 3965 | 88[w] | 2.42 | 11.1[v] | 11.1 | 0.392 | 30 | 86 |
| | 3 | 36.8 | 18.7 | 3673 | 94 | 2.47 | 11.2[v] | 11.0 | 0.387 | 30 | 86 |
| Test Average | | 35.1 | 19.2 | 3780 | | | | | | | |

[z] 227 kg (500 lb) equivalent bales

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

[x] Mote cleaner system exhaust was combined with a module feeder dust system exhaust

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

[v] Did not meet $PM_{10}$ (10.0 ± 1.0 µm) aerodynamic cut size criteria

No system averages were calculated, because the gin F mote cleaner system was combined with a module feeder dust system that could significantly impact the mote cleaner system emissions. $PM_{2.5}$ emissions data (ginning and emission rates and corresponding emission factors) for the mote cleaner systems are shown in Table 3. The test average $PM_{2.5}$ emission factor based on the three test runs at gin F was 0.022 kg/bale (0.050 lb/bale) and ranged from 0.017 to 0.029 kg (0.038-0.065 lb) per bale. The average $PM_{2.5}$ emission rate for gin F test runs was 1.07 kg/h (2.35 lb/h). The test average $PM_{2.5}$ emission factor based on the three test runs at gin G was 0.0036 kg/bale (0.0079 lb/bale) and ranged from 0.0034 to 0.0041 kg (0.0074 to 0.0089 lb) per bale. The average $PM_{2.5}$ emission rate for gin G test runs was 0.13 kg/h (0.28 lb/h). $PM_{10}$ emissions data (ginning and emission rates and corresponding emission factors) for the mote cleaner systems are shown in Table 4, but no averages were calculated because $PM_{10}$ cut size criteria was not met in this $PM_{2.5}$ targeted testing. Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the mote cleaner systems are shown in Table 5. The test average total particulate emission factor for gin G was 0.065 kg/bale (0.14 lb/bale) and emission rate was 2.32 kg/h (5.13 lb/h). The ratio of $PM_{2.5}$ to total particulate for gin G was 5.5% (this ratio was calculated using tables 3 and 5, and may vary slightly from those listed due to rounding). No average total particulate emission factor or ratio of $PM_{2.5}$ to total particulate could be calculated for gin F, because the total particulate isokinetic criterion was not met.

The mote cleaner system total particulate emission factor determined for gin G (the stand alone mote cleaner system) was about 40% of the combined EPA AP-42 published values for the mote fan and mote trash fan (EPA, 1996a, 1996b), which would be similar to the mote cleaner system. The range of gin G mote cleaner system test average total particulate emission factors fell within the range of AP-42 emission factor data for the mote fan and was higher than the AP-42 data range for the mote trash fan.

**Table 3. $PM_{2.5}$ emissions data for the mote cleaner systems.**

| Gin | Test Run | Emission Rate | | Emission Factor | |
|---|---|---|---|---|---|
| | | kg/h | lb/h | kg/bale[z] | lb/bale[z] |
| F[y] | 1 | 0.80 | 1.77 | 0.017 | 0.038 |
| | 2 | 1.35 | 2.97 | 0.029 | 0.065 |
| | 3 | 1.05 | 2.31 | 0.021 | 0.046 |
| Test Average (n=3) | | 1.07 | 2.35 | 0.022 | 0.050 |
| G | 1 | 0.14 | 0.31 | 0.0041 | 0.0089 |
| | 2 | 0.12 | 0.25 | 0.0034 | 0.0074 |
| | 3 | 0.12 | 0.27 | 0.0034 | 0.0074 |
| Test Average (n=3) | | 0.13 | 0.28 | 0.0036 | 0.0079 |

[z] 227 kg (500 lb) equivalent bales

[y] Mote cleaner system exhaust was combined with a module feeder dust system exhaust

**Table 4. $PM_{10}$ emission data for the mote cleaner systems.**

| Gin | Test Run | Emission Rate | | Emission Factor | |
|---|---|---|---|---|---|
| | | kg/h | lb/h | kg/bale[z] | lb/bale[z] |
| F[y] | 1[x] | 3.91 | 8.63 | 0.084 | 0.18 |
| | 2[x] | 3.14 | 6.92 | 0.068 | 0.15 |
| | 3[x] | 3.60 | 7.93 | 0.072 | 0.16 |
| Test Average (n=0) | | | | | |
| G | 1[x] | 0.79 | 1.75 | 0.023 | 0.051 |
| | 2[x] | 1.99 | 4.38 | 0.058 | 0.13 |
| | 3[x] | 1.85 | 4.08 | 0.050 | 0.11 |
| Test Average (n=0) | | | | | |

[z] 227 kg (500 lb) equivalent bales

[y] Mote cleaner system exhaust was combined with a module feeder dust system exhaust

[x] Test run omitted from test averages because aerodynamic cut size (10.0 ± 1.0 µm) was not met

**Table 5. Total particulate emission data for the mote cleaner systems.**

| Gin | Test Run | Emission Rate | | Emission Factor | |
|---|---|---|---|---|---|
| | | kg/h | lb/h | kg/bale[z] | lb/bale[z] |
| F[y] | 1[x] | 6.02 | 13.28 | 0.13 | 0.28 |
| | 2[x] | 4.54 | 10.00 | 0.099 | 0.22 |
| | 3[x] | 5.21 | 11.49 | 0.10 | 0.23 |
| Test Average (n=0) | | | | | |
| G | 1 | 1.67 | 3.68 | 0.049 | 0.11 |
| | 2[x] | 3.26 | 7.18 | 0.095 | 0.21 |
| | 3 | 2.98 | 6.57 | 0.081 | 0.18 |
| Test Average (n=2) | | 2.32 | 5.13 | 0.065 | 0.14 |

[z] 227 kg (500 lb) equivalent bales

[y] Mote cleaner system exhaust was combined with a module feeder dust system exhaust

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

Figure 13 shows an example of samples recovered from a typical mote cleaner 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 14, lint fibers passed through the $PM_{10}$ and $PM_{2.5}$ cyclones and collected in the 10 to 2.5 µm wash 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.

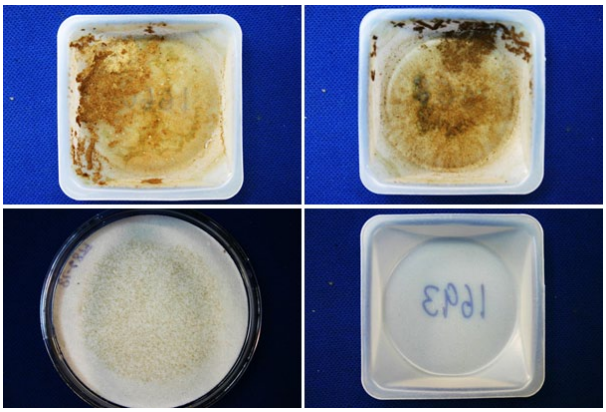

**Figure 13. Typical EPA Method 201A filter and sampler head acetone washes from the mote cleaner systems. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.**

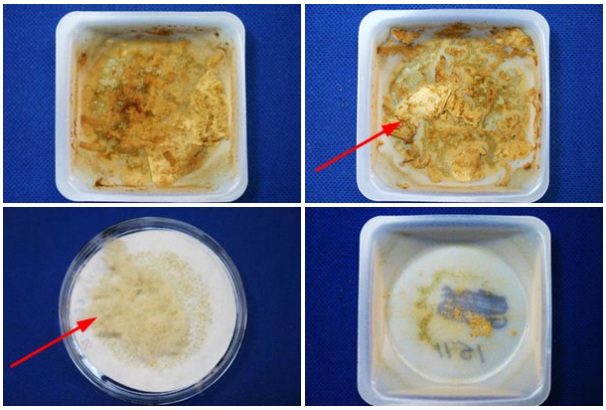

**Figure 14. Atypical EPA Method 201A filter and sampler head acetone washes from the mote cleaner systems with lint in the 10 to 2.5 µm wash and on the filter. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.**

## 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. Two of the seven gins had mote cleaner systems. The exhaust from one of the mote cleaner systems was combined with the module feeder dust system. The tested systems were similar in design and typical of the ginning industry. All the systems were equipped with 1D3D cyclones for emissions control. The ginning rate of the two gins averaged 35.1 and 47.6 bales/h during testing for the standalone mote cleaner system and mote cleaner and module feeder dust system, respectively. 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 $PM_{2.5}$ and total emission factors for the stand-alone mote cleaner system were 0.0036 kg/227-kg bale (0.0079 lb/500-lb bale) and 0.065 kg/bale (0.14 lb/bale). The average total particulate emission factor for the stand-alone mote cleaner system was lower than those currently published in EPA AP-42 for similar systems. The ratio of mote cleaner system $PM_{2.5}$ to total particulate was 5.5%. Average measured $PM_{2.5}$ emission factors for the mote cleaner system combined with the module feeder dust system was 0.022 kg/bale (0.050 lb/bale); no total particulate emission factor was reported because isokinetics were not met. These data are the first published data to document $PM_{2.5}$ emissions from mote cleaner systems at cotton gins.

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