The *Journal of Cotton Science 19:150–158 (2015)*
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ENGINEERING AND GINNING

Mote Cyclone Robber System Total Particulate Emission Factors and Rates for Cotton Gins: Method 17

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ABSTRACT

This report is part of a project to characterize cotton gin emissions from the standpoint of stack sampling. The impetus behind this project was the urgent need to collect additional cotton gin emissions data to address current regulatory issues. A key component of this study was focused on Environmental Protection Agency (EPA) total particulate emission factors. There is no total particulate emission factor published for mote cyclone robber systems in the 1996 EPA AP-42. The objective of this study was to collect total particulate emission factor data for mote cyclone robber cleaning systems from cotton gins located in regions across the cotton belt using EPA-approved stack sampling methodology. The project plan included sampling seven cotton gins. Key factors for selecting specific cotton gins included: 1) facility location, 2) production capacity, 3) processing systems and 4) abatement technologies. Three gins with mote cyclone robber systems were sampled. The average production rate during testing for the three gins was 25.6 bales/h. The average mote cyclone robber system total particulate emission factor based on three tests (nine total test runs) was 0.050 kg/227-kg bale (0.111 lb/500-lb bale). The mote cyclone robber systems emission rate test averages ranged from 0.66 to 2.15 kg/h (1.46-4.74 lb/h).

United States (U.S.) Environmental Protection Agency (EPA) emission factors were published in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996b). These factors were assigned a rating from A (Excellent) to E (Poor) that is used to assess the quality of the data being referenced. In the 1996 EPA AP-42, there are emission factors for total particulate listed for eleven common cotton gin systems. The EPA emission factor quality ratings for these data are extremely low. Cotton gin data received these low ratings because they were collected almost exclusively from a single geographical region, far western United States (EPA, 1996a). The AP-42 data are limited in that some systems commonly used in cotton gins are not represented or are combined with another system under a single emission factor (e.g. 1st and 2nd stage lint cleaning are represented by lint cleaners). Cotton ginners' associations across the cotton belt, including the National, Texas, Southern, Southeastern, and California associations, agreed that there was an urgent need to collect additional cotton gin emissions data to address current regulatory issues. Working with the cotton ginning associations across the country and state and federal regulatory agencies, Oklahoma State University and United States Department of Agriculture-Agricultural Research Service (USDA-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 total particulate emissions from mote cyclone robber systems.

There were no 1996 EPA AP-42 average emission factors for the mote cyclone robber systems. The two systems listed in AP-42 that were similar to the mote cyclone robber were the cyclone robber and

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mote fan (EPA, 1996a, 1996b). The AP-42 total particulate emission factor for the cyclone robber was 0.083 kg (0.18 lb) per 217-kg [480-lb]; this factor was based on one test. The AP-42 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 to 1.0 lb) per bale. This average and range was based on nine tests conducted in one geographical location. The EPA emission factor quality rating for both the cyclone robber and mote fan was D, which is the second lowest possible rating (EPA, 1996a). Based on the system design, it would be expected that the mote cyclone robber would have lower emission factors than the mote fan and higher emission factors than the cyclone robber.

Seed-cotton is a perishable commodity that has no real value until the fiber and seed are separated (Wakelyn et al., 2005). Cotton must first 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 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, annual production 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, but has instead steadily declined to fewer than 700 in 2011. Consequently, the average volume of cotton handled by each gin has risen and gin capacity has increased to an average of about 25 bales per hour across the U.S. cotton belt (Valco et al., 2003, 2006, 2009, 2012).

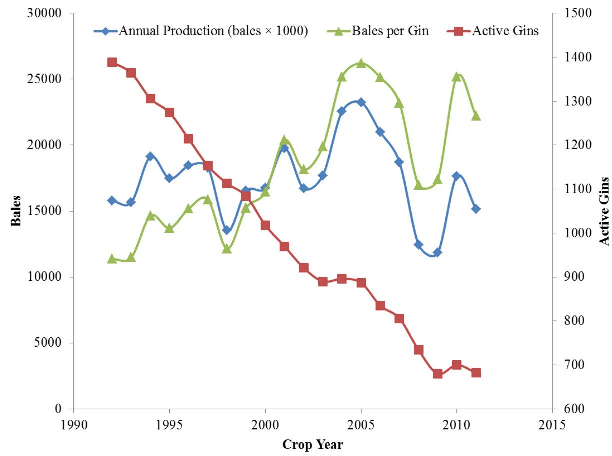

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

The typical cotton gin facility includes: 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 varies. Each of these systems serves a unique function with the ultimate goal of ginning the cotton to produce a marketable product. Raw seed-cotton harvested from the field is compacted into large units called modules for delivery to the gin. The unloading system removes seed-cotton either mechanically or pneumatically from the module feed system and conveys the seed-cotton to the seed-cotton cleaning systems. Seed-cotton cleaning systems dry the seed-cotton and remove foreign matter prior to ginning. Ginning systems also remove foreign matter and separate the cotton fiber from the seed. Lint cleaning systems further clean the cotton lint after ginning. The battery condenser and packaging systems combine lint from the lint cleaning systems and compress the lint into dense bales for easy transport. Gin systems produce some type of by-product or trash, such as rocks, soil, sticks, hulls, leaf material, and short or tangled immature fiber (motes), as a result of processing the seed-cotton or lint. These streams of by-products must be removed from the machinery and handled by trash collection systems. These trash systems typically further process the by-products (e.g., mote cleaners) and/or consolidate the trash from the gin systems into a hopper or pile for subsequent removal.

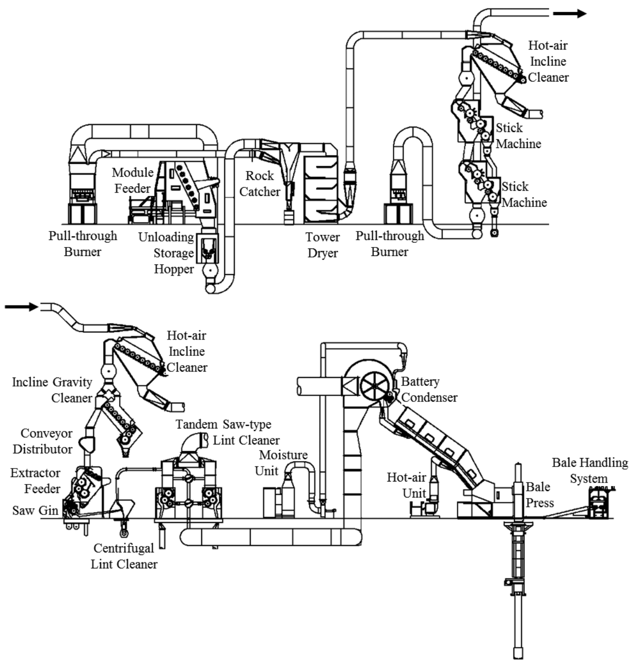

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

Mote cyclone robber systems are typically used to remove material captured by the mote system cyclones (waste streams from the lint cleaning systems) (Fig. 3) and may also remove material from cyclones controlling emissions from lint conveying systems (lint cleaning and battery condenser). Material captured by these cyclones must be handled and conveyed from the trash exit of the cyclone or the materials would build up and eventually choke or block the airflow in the cyclone, reducing or stopping its cleaning ability. In the case of cyclones that handle airstreams laden with higher amounts of lint (mote system cyclones), it may not be practical to convey the high-lint-content material mechanically, as then lint tends to "rope-up" and collect on the moving parts. Also, this high-lint-content material, referred to as motes, has considerable value, especially when cleaned. Thus this material is pulled by suction from the trash exit of the cyclones and pneumatically conveyed via a mote cyclone robber system to another cyclone that drops the motes directly into a machine for cleaning. The material handled by the mote cyclone robber cyclones typically includes small trash and particulate and large amounts of lint fibers (Fig. 4).

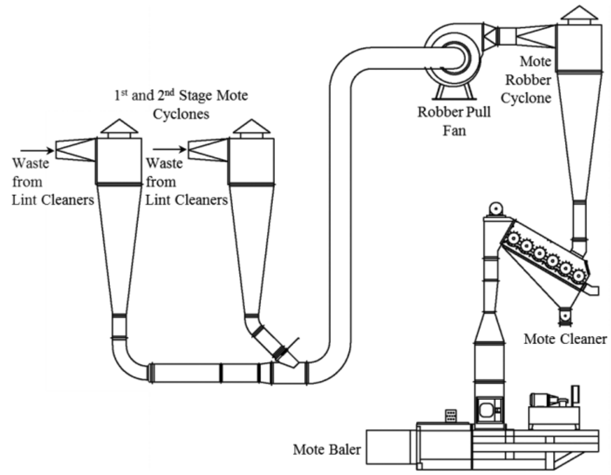

Figure 3. Typical cotton gin mote cyclone robber system layout (Courtesy Lummus Corporation, Savannah, GA).

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

Cyclones are the most common particulate matter (PM) 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).

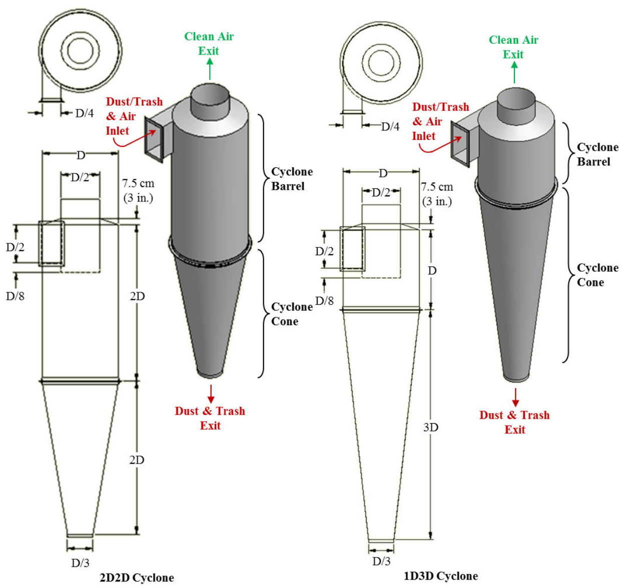

Figure 5. 2D2D and 1D3D cyclone schematics.

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

METHODS

Two advisory groups were established for this project. The industry group consisted of cotton ginning industry leaders and university and government researchers. The air quality group included members from state and federal regulatory agencies, and university and government researchers. 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 cotton gins were sampled across the cotton belt. Key factors for selecting specific cotton gins included: 1) facility location, 2) production capacity, 3) processing systems and 4) abatement technologies. Operating permits, site plans, and aerial photographs were reviewed to evaluate potential sites. On-site visits were conducted at all candidate gins to evaluate the process systems and gather information including system condition, layout, capacities, and standard operation. Using this information, several gins from each selected geographical region were selected and prioritized based on industry advisory group discussions. Final gin selection from the prioritized list was influenced by crop limitations and adverse weather events in the region.

Based on air quality advisory group consensus, EPA Method 17 (CFR, 1978) was used to sample the mote cyclone robber system at each gin. Method 17 was selected over Method 5 (CFR, 1987) because of the relatively low stack temperatures found at cotton gins. Method 5 requires a heated glass probe and filter holder to maintain the sampled gas temperature of 120°C (248°F). Key benefits of using Method 17 over Method 5 occur when particulate concentrations are independent of temperature and the sampled gas contains no liquid droplets or is not saturated with water vapor, the heating systems can be eliminated and sampling can occur at stack temperature with an in-stack filter. Methodology for sampling total particulate called for withdrawing particulate-laden stack gas isokinetically (the velocity of the gas entering the sampler was equal to the velocity of the gas in the stack) through a button-hook nozzle and then collecting particles on an in-stack filter (Fig. 6). The methods for retrieving the filter and conducting acetone washes of the sampling nozzle are described in Method 17 (CFR, 1978). The mass of particulate on the filter and in the nozzle wash was determined by gravimetric analyses. The total particulate mass was determined by summing the mass of particulates on the filter and the front half wash. Stack gas temperature and moisture content were also measured using EPA Method 17.

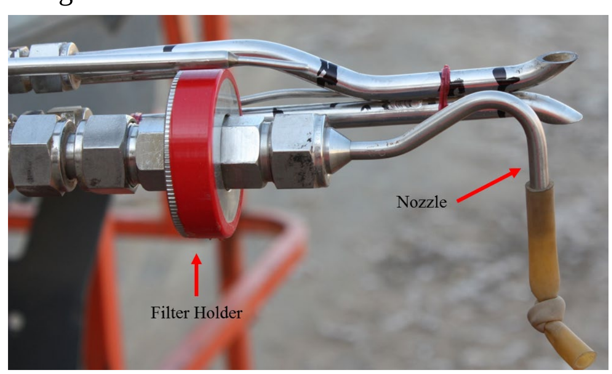

Figure 6. EPA Method 17 total particulate button-hook nozzle and in-stack filter holder photograph.

Only one stack from each first stage seed-cotton cleaning system was tested. For systems with multiple stacks, it was assumed that emissions from each stack of the system were equivalent. The total particulate emissions for the system 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 all the tests at all the cotton gins.

All stack sampling equipment was purchased from Apex Instruments (Fuquay-Varina, NC) and met Method 17 specifications. 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-Agricultural Research Service Air Quality Lab (AQL) in Lubbock, TX, and then transported to each test site. Prior to testing, the technician calibrated all sampling equipment according to EPA Method 17.

Each cyclone selected for testing was fitted with a cyclone stack extension that incorporated two sampling ports (90° apart) and airflow straightening vanes to eliminate the cyclonic flow of the air exiting the cyclone (Fig. 7). 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.

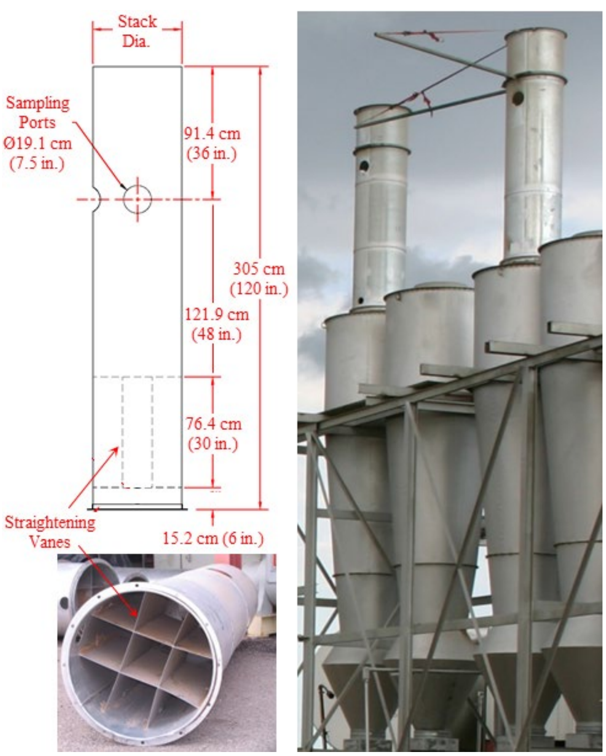

Figure 7. Schematic and photographs of stack extensions with sampling port and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

The tests were conducted by the technician in an enclosed sampling trailer at the base of the cyclone bank (Fig. 8). Sample retrieval, including filters and nozzle acetone washes, was conducted according to Method 17. 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 17 and American Society of Agricultural Engineers (ASAE) Standard S582 (ASABE, 2005).

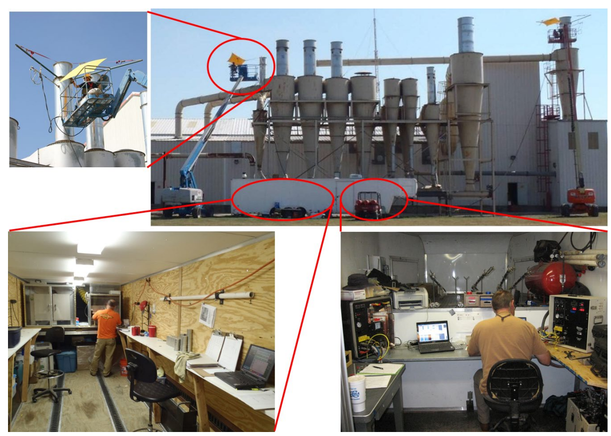

Figure 8. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber (21 ± 2ºC [70 ± 3.6ºF]; 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 electronically transferred from the microbalance directly to a spreadsheet. Technicians wore latex gloves and a particulate respirator mask to avoid contamination. AQL procedures required that each sample be weighed three times. If the standard deviation of the weights for a given sample exceeded 10 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. After the laboratory analyses were completed all stack sampling, cotton gin production, and laboratory data were merged.

Three of the seven gins (A, B and D) sampled had mote cyclone robber systems. The mote cyclone robber systems sampled were typical for the industry, but varied among the gins. The mote cyclone robber system at gins A and D pneumatically conveyed lint laden trash from the cyclones for the 1st stage mote system and the 2nd stage mote system (waste streams from the 1st and 2nd stage lint cleaning systems) through a fan to a cyclone that dropped the trash into a machine for cleaning and packaging (Fig. 9). The mote cyclone robber system at gin B was similar, except it also picked up lint laden trash from the cyclones for two 2nd stage lint cleaner systems (Fig. 10).

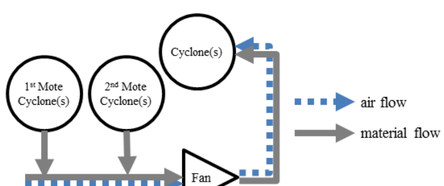

Figure 9. Schematic of mote cyclone robber system pulling material from the first and second stage mote system cyclones (gins A and D).

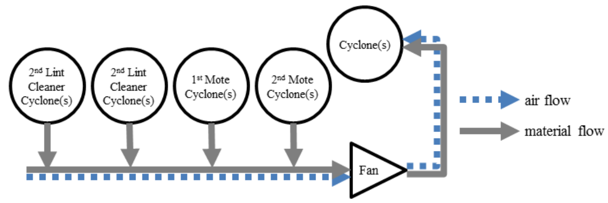

Figure 10. Schematic of mote cyclone robber system pulling material from the first and second stage mote system cyclones and two 2nd stage lint cleaner system cyclones (gin B).

All mote cyclone robber systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among the gins (Table 1 and Fig. 11). Gin B split the system exhaust flow between two cyclones in a dual configuration (side-by-side as opposed to one-behind-another). The system air stream for gins A and D were exhausted through a single cyclone. Inlets on all the mote cyclone robber cyclones were 2D2D type, except the cyclone at gin A that had an inverted 1D3D inlet. Expansion chambers were present on mote cyclone robber cyclones for gin B. Gins A and D had standard cones. All of the cyclone variations outlined above, if properly designed and maintained, are recommended for controlling cotton gin emissions (Whitelock et al., 2009).

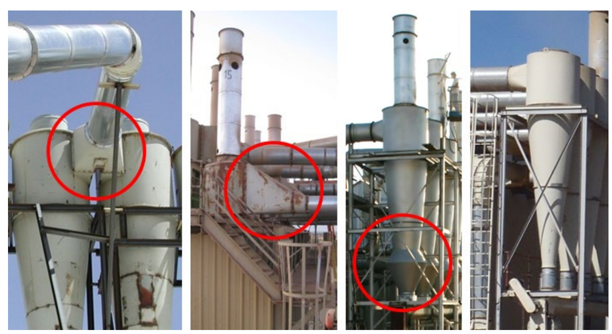

Figure 11. Cyclone design variations for the tested systems (left to right): dual configuration that splits flow between identical 1D3D cyclones with 2D2D inlets; 1D3D cyclone with an inverted 1D3D inlet; 1D3D cyclone with 2D2D inlet and expansion chamber on the cone; 1D3D cyclone with 2D2D inlet and standard cone.

Table 1. Abatement device configuration[z] for mote cyclone robber systems tested.

Gin	Cyclone Type	Inlet Design[y]	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash Exit[x]
A	1D3D	inverted 1D3D	1	1	single	standard	mote cleaner
B	1D3D	2D2D	1	2	dual	expansion chamber	mote cleaner
D	1D3D	2D2D	1	1	single	standard	mote cleaner

[z] Figures 5 and 12

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

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

RESULTS

Table 2 shows the test parameters for each Method 17 test run for the mote cyclone robber systems sampled at the three gins. The system average ginning rate was 25.6 bales/h and the test average ginning rate at each gin ranged from 21.2 to 31.5 bales/h (based on 227-kg [500-lb] equivalent bales). The capacity of gins sampled was representative of the industry average, approximately 25 bales/h. The 1D3D cyclones were all operated with inlet velocities within design criteria, 16.3 ± 2 m/s (3200 ± 400 fpm), except test run three at gins B and D that were outside the design range due to limitations in available system adjustments.

There are criteria specified in EPA Method 17 for test runs to be valid for total particulate measurements (CFR, 1978). Isokinetic sampling must fall within the EPA defined range of 100 ± 10%. All tests met the isokinetic criteria (Table 2). The stack gas temperatures ranged from 17 to 41°C (62-105°F) and moisture content ranged from 1.1 to 3.2% wet basis (w.b.).

Total particulate emissions data (emission rates and corresponding emission factors) for the mote cyclone robber systems are shown in Table 3. The system average emission factor for the three gins was 0.050 kg/bale (0.111 lb/bale). The test average emission factors ranged from 0.034 to 0.070 kg (0.075-0.155 lb) per bale. The average mote cyclone robber system total particulate emission factor for this project was about 61.5% of that published in the current 1996 EPA AP-42 for the cyclone robber system (0.083 kg/bale [0.18 lb/bale]) and 39.5% of that published for the mote fan (0.13 kg/bale [0.28 lb/bale]) (EPA, 1996a, b). The range of test average total particulate emission factors determined for this project and the AP-42 emission factor data range for the mote fan overlapped. The test average emission rates ranged from 0.66 to 2.15 kg/h (1.46-4.74 lb/h).

Figure 12 shows an example of samples recovered from a mote cyclone robber system test run. Often, there were cotton lint fibers in the cotton gin cyclone exhausts. Therefore, it was not unusual to find lint fiber on the Method 17 filter or in the front half wash, which was included in the total particulate emissions.

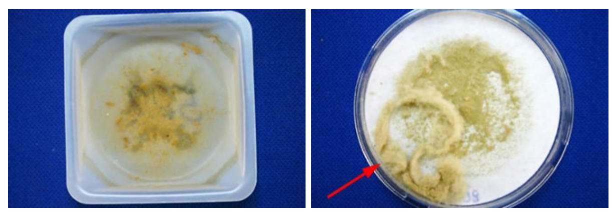

Figure 12. Typical EPA Method 17 filter and sampler head acetone wash from the mote cyclone robber system with lint on the filter (indicated by arrow). From left to right: front half wash and filter.

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

Gin	Test Run	Ginning Rate, bales/h[z]	Cyclone Inlet Velocity,		Isokinetic Sampling, %	Stack Moisture, % w.b.	Stack Temperature	
			m/s	fpm			°C	°F
A	1	23.4	15.6	3067	103	3.2	22	71
	2	23.2	15.9	3129	99	1.7	19	66
	3	26.0	15.7	3099	98	2.2	17	62
Test Average		24.2	15.7	3098				
B	1	25.5	14.6	2884	97	1.6	39	103
	2	12.0	14.6	2866	97	2.3	41	105
	3	26.0	14.1	2785	100	3.0	40	104
Test Average		21.2	14.5	2845				
D	1	32.7	17.8	3506	97	1.1	33	91
	2	34.4	18.0	3544	96	1.2	33	92
	3	27.3	18.4	3619	95	1.1	23	73
Test Average		31.5	18.1	3557				
System Average		25.6	16.1	3167				

[z] 227 kg (500 lb) equivalent bales

Table 3. Total particulate emissions data for the mote cyclone robber systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	1.12	2.47	0.048	0.106
	2	1.13	2.49	0.049	0.107
	3	1.11	2.45	0.043	0.094
Test Average (n=3)		1.12	2.47	0.046	0.102
B	1	0.53	1.17	0.021	0.046
	2	0.56	1.23	0.047	0.103
	3	0.89	1.97	0.034	0.076
Test Average (n=3)		0.66	1.46	0.034	0.075
D	1	1.20	2.63	0.037	0.081
	2	2.42	5.33	0.070	0.155
	3	2.83	6.24	0.104	0.229
Test Average (n=3)		2.15	4.74	0.070	0.155
System Average (n=3)				0.050	0.111

[z] 227 kg (500 lb) equivalent bales

SUMMARY

Three cotton gins with mote cyclone robber systems were sampled using EPA Method 17 to collect total particulate emission factor data for cotton gins. The tested systems were similar in design and typical of the ginning industry. The system exhausts were equipped with 1D3D cyclones for emissions control with some variations in inlet and cone design. The average production rate during testing for the three gins was 25.6 bales/h. The average mote cyclone robber system total particulate emission factor based on the three gins tested (nine total test runs) was 0.050 kg/227-kg bale (0.111 lb/500-lb bale). The gin test average emission rates ranged from 0.66 to 2.15 kg/h (1.46-4.74 lb/h).

ACKNOWLEDGEMENT

The authors appreciate the cooperating gin managers and personnel who generously allowed and endured sampling at their gins. In addition, we thank California Cotton Ginners' and Growers' Association, Cotton Incorporated, San Joaquin Valleywide Air Pollution Study Agency, Southeastern Cotton Ginners' Association, Southern Cotton Ginners' Association, Texas Cotton Ginners' Association, Texas State Support Committee, and The Cotton Foundation for funding this project. This project was support in-part by the USDA National Institute of Food and Agriculture Hatch Project OKL02882. The authors also thank the Cotton Gin Advisory Group and Air Quality Advisory Group for their involvement and participation in planning, execution, and data analysis for this project that is essential to developing quality data that will be used by industry, regulatory agencies, and the scientific community. The advisory groups included: the funding agencies listed above, California Air Resources Board, Missouri Department of Natural Resources, National Cotton Council, National Cotton Ginners' Association, North Carolina Department of Environment and Natural Resources, San Joaquin Valley Air Pollution Control District, Texas A&M University, Texas Commission on Environmental Quality, USDA-NRCS National Air Quality and Atmospheric Change, and U.S. Environmental Protection Agency (national, Region 4 and 9).

DISCLAIMER

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The statements and conclusions in this report are those of the USDA-ARS and Oklahoma State University and not necessarily those of the California Air Resources Board, the San Joaquin Valleywide

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