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ENGINEERING & GINNING

Second Stage Mote 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 factors published for 2nd stage mote systems in the 1996 EPA AP-42. The current AP-42 factor represents 1st and 2nd stage mote systems combined. The objective of this study was to collect total particulate emission factor data for 2nd stage mote 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. Five gins with 2nd stage mote system exhausts that were not combined with 1st stage system exhausts were sampled. The average production rate during testing for the five gins was 29.5 bales/h. The average 2nd stage mote system total particulate emission factor based on five tests (15 total test runs) was 0.011 kg/227-kg bale (0.023 lb/500-lb bale). The test average 2nd stage mote system emission rates ranged from 0.16 to 0.71 kg/h (0.34-1.56 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, the 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 2nd stage mote systems.

There are no 1996 EPA AP-42 emission factors for 2nd stage mote systems (EPA, 1996b). Second stage mote systems would be similar to the mote fan listed in AP-42, but the AP-42 factor represents 1st and 2nd stage mote systems combined. The 1996 EPA AP-42 average total

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particulate emission factor for the mote fan (1st and 2nd mote systems combined) was 0.13 kg (0.28 lb) per 217-kg [480-lb] equivalent bale with a range of 0.045 to 0.47 kg (0.099-1.0 lb) per bale (EPA, 1996a, 1996b). This average and range was based on nine tests conducted in one geographical location. The EPA emission factor quality rating was D, which is 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 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 instead has 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).

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.

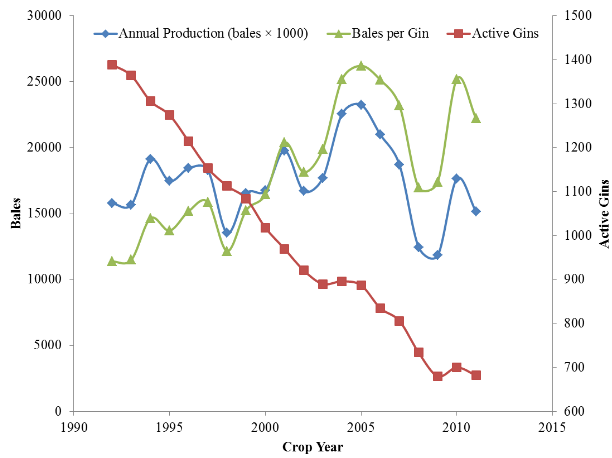

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

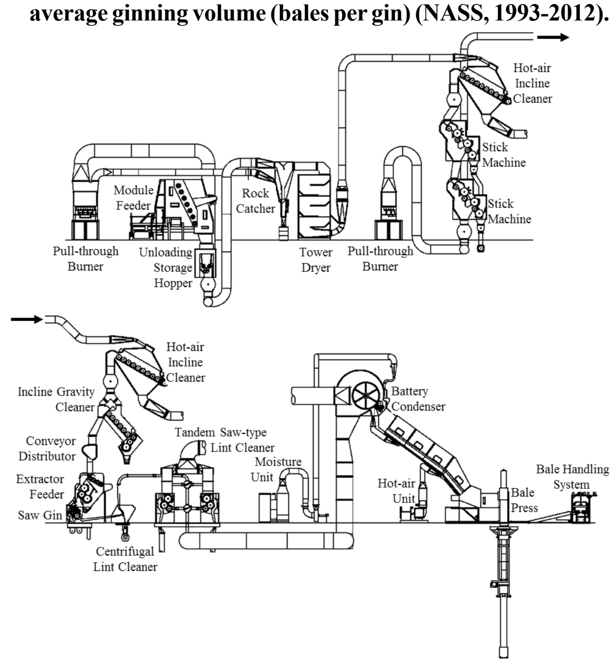

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

After the seed and lint are separated at the gin stand, the lint is cleaned by one or more stages of lint cleaners. The material removed by lint cleaners is referred to as motes and is handled by the mote systems (Fig. 3). Motes are pneumatically conveyed by suction away from the lint cleaners, through a centrifugal fan, to one or two particulate abatement cyclones. Depending on the gin facility, the 1st and 2nd stages of lint cleaning may share a mote system, thus sharing a fan and abatement devices, or lint cleaning stages may have mote systems that operate independently with separate fans and cyclones, denoted as 1st stage mote systems or 2nd stage mote systems. The material handled by the mote cyclones typically includes small trash and particulate, and large amounts of lint fibers (Fig. 4).

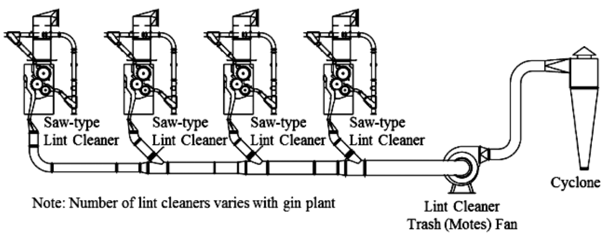

Figure 3. Typical cotton gin second stage mote system layout (Courtesy Lummus Corporation, Savannah, GA).

Figure 4. Photograph of typical trash captured by the second stage mote 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).

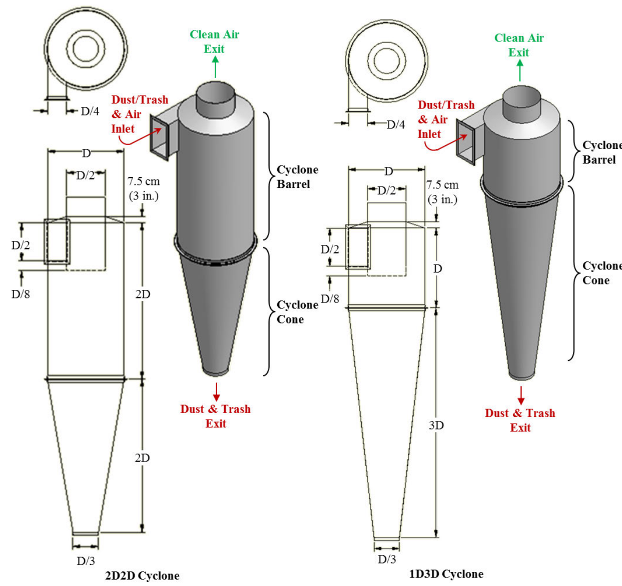

Figure 5. 2D2D and 1D3D cyclone schematics.

The objective of this study was to collect total particulate emission factor data for 2nd stage mote 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 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, 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 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 Method 17 (CFR, 1978) was used to sample the 2nd stage mote 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 are where 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.

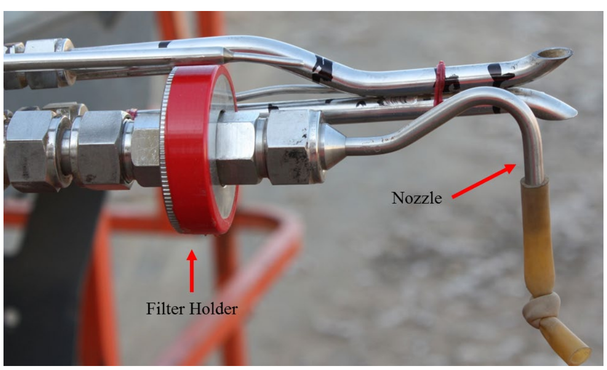

Figure 6. EPA Method 17 total particulate button-hook nozzle and in-stack filter holder photograph.

Only one stack from each 2nd stage mote 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-ARS 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.

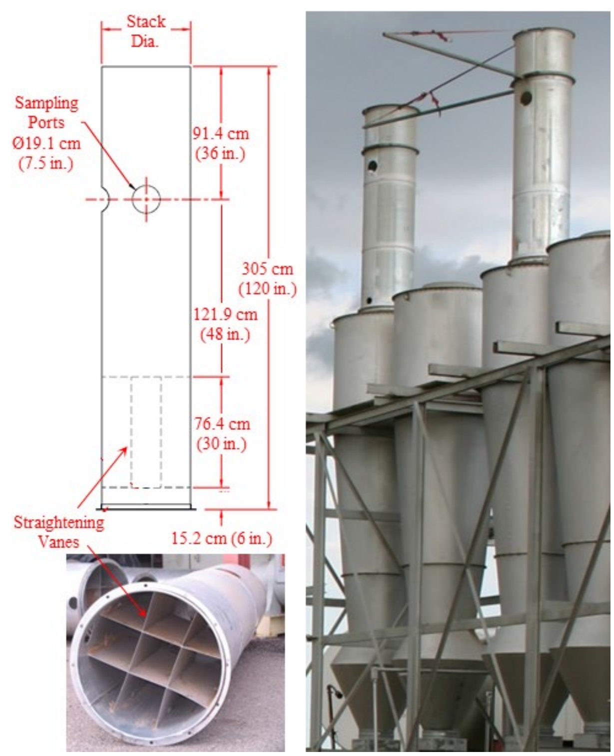

Figure 7. Schematic and photographs of stack extensions with sampling port and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

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).

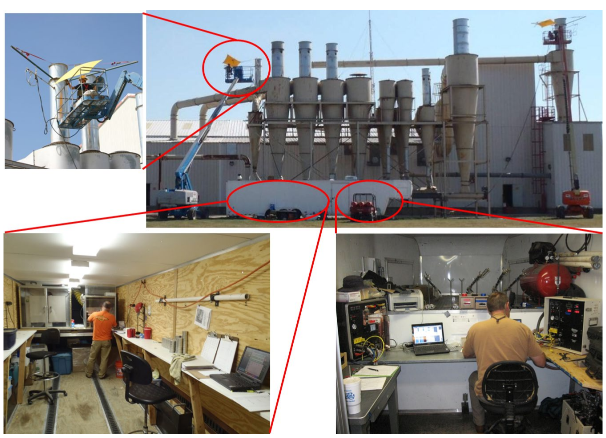

Figure 8. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

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.

Five of the seven gins (A, B, C, D and F) sampled had 2nd stage mote systems. The 2nd stage mote systems sampled were typical for the industry, but varied among the gins. After the 1st stage lint cleaning systems, the lint was cleaned a second time in three 2nd stage lint cleaning systems at gin A. The trash removed from the lint in the 2nd stage lint cleaning systems was combined in the 2nd stage mote system and pneumatically conveyed from the lint cleaners through a fan and exhausted through one or more cyclones (Fig. 9). The 2nd stage mote system at gin C was essentially the same, except the 2nd stage mote system pulled trash from two 2nd stage lint cleaning systems (Fig. 10). At gin B, the 2nd stage mote system was similar to that at gin C, but each 2nd stage lint cleaning system processed lint from double 1st stage lint cleaning systems (Fig. 11). The 2nd stage mote systems at gins D and F were also similar, but the systems at those gins pulled material from four 2nd stage lint cleaning systems (Fig. 12).

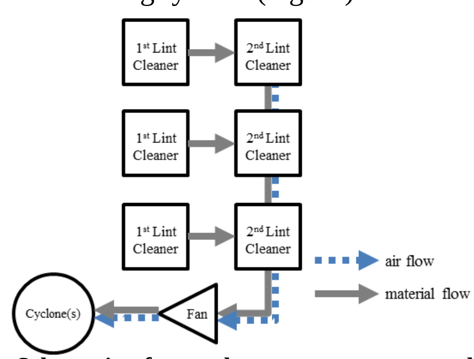

Figure 9. Schematic of second stage mote system pulling material from three second stage lint cleaners (gin A).

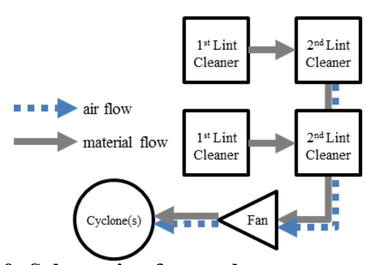

Figure 10. Schematic of second stage mote system pulling material from two second stage lint cleaners (gin C).

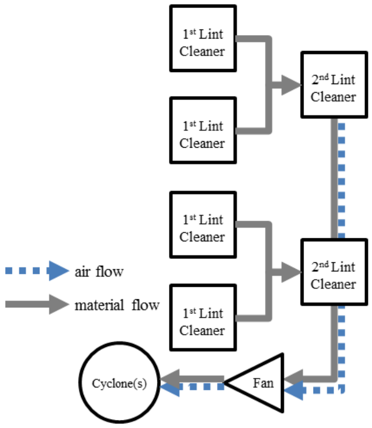

Figure 11. Schematic of second stage mote system pulling material from two second stage lint cleaners each preceded by double first stage lint cleaners (gin B).

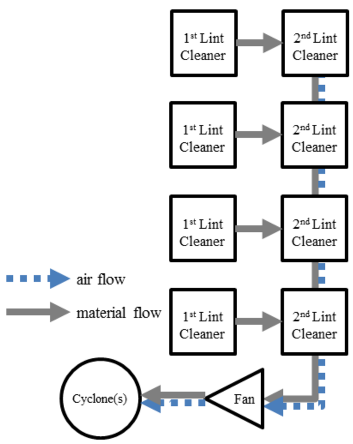

Figure 12. Schematic of second stage mote system pulling material from four second stage lint cleaners (gins D and F).

All 2nd stage mote systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among the gins (Table 1 and Fig. 13). All the gins, except 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 airstream for gin B was exhausted through a single cyclone. Inlets on all the 2nd stage mote cyclones were 2D2D type, except the cyclones at gin A that had inverted 1D3D inlets. Standard cones were present on 2nd stage mote cyclones at all gins, except gins B and C that had expansion chambers. The cyclones tested at gins A, B, D, and F had mote cyclone robber systems pulling airflow from their exits. This configuration helps remove lint and other trash from the cyclone that could otherwise circulate near the trash exit at the bottom of the cone for a period of time before dropping out. All of the cyclone variations outlined above, if properly designed and maintained, are recommended for controlling cotton gin emissions (Whitelock et al., 2009).

Figure 13. 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 second stage mote 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	2	dual	standard	robber
B	1D3D	2D2D	1	1	single	expansion chamber	robber
C	1D3D	2D2D	1	2	dual	expansion chamber	hopper
D	1D3D	2D2D	1	2	dual	standard	robber
F	1D3D	2D2D	1	2	dual	standard	robber

[z] Figures 5 and 13

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

[x] Systems to remove material from cyclone trash exits: hopper = large storage container directly under cyclone trash exit; robber = pneumatic suction system

RESULTS

Table 2 shows the test parameters for each Method 17 test run for the 2nd stage mote systems sampled at the five gins. The system average ginning rate for the five gins was 29.5 bales/h and the test average ginning rate at each gin ranged from 18.4 to 44.3 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 the first and second test runs at gin A 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 18 to 46°C (64-114°F) and moisture content ranged from 0.2 to 4.5% w.b.

Total particulate emissions data (emission rates and corresponding emission factors) for the 2nd stage mote systems are shown in Table 3. The system average emission factor for the five gins was 0.011 kg/bale (0.023 lb/bale). The test average emission factors ranged from 0.0070 to 0.019 kg (0.015-0.042 lb) per bale. The average 2nd stage mote system total particulate emission factor for this project was about 8% of that published in the current 1996 EPA AP-42 for the mote fan (0.13 kg/bale [0.28 lb/bale]) (EPA, 1996a, b), which is an equivalent system to a combined 1st and 2nd stage mote system. The range of test average total particulate emission factors determined for this project was lower than the AP-42 emission factor data range for the mote fan. The test average emission rates ranged from 0.16 to 0.71 kg/h (0.34-1.56 lb/h).

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

Gin	Test Run	Ginning Rate, bales/h[z]	Cyclone Inlet Velocity,		Isokinetic Sampling, %	Stack Gas		
						Moisture Content, % w.b.	Temperature	
			m/s	fpm			°C	°F
A	1	24.5	14.1	2776	101	2.0	21	70
	2	17.9	13.6	2671	102	0.8	18	65
	3	20.1	14.2	2801	100	0.2	18	65
Test Average		20.8	14.0	2749				
B	1	28.6	15.5	3055	107	4.5	40	105
	2	29.2	15.8	3115	105	4.5	40	103
	3	22.8	15.5	3046	105	3.5	38	100
Test Average		26.8	15.6	3072				
C	1	18.9	14.5	2859	99	2.4	21	70
	2	17.4	14.4	2834	100	2.4	24	75
	3	19.1	14.3	2807	102	2.2	27	81
Test Average		18.4	14.4	2833				
D	1	38.0	16.1	3166	95	1.4	32	89
	2	34.9	15.9	3139	93	1.0	18	64
	3	37.8	16.1	3175	97	1.6	21	70
Test Average		36.9	16.1	3160				
F	1	40.4	15.2	2985	93	0.8	41	105
	2	45.4	14.9	2942	93	2.5	44	111
	3	47.0	14.7	2886	93	1.5	46	114
Test Average		44.3	14.9	2938				
System Average		29.5	15.0	2950				

[z] 227 kg (500 lb) equivalent bales

Table 3. Total particulate emissions data for the second stage mote systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.20	0.44	0.0082	0.018
	2	0.12	0.26	0.0067	0.015
	3	0.16	0.35	0.0079	0.017
Test Average (n=3)		0.16	0.35	0.0076	0.017
B	1	0.32	0.70	0.011	0.024
	2	0.35	0.77	0.012	0.026
	3	0.20	0.45	0.0089	0.020
Test Average (n=3)		0.29	0.64	0.011	0.023
C	1	0.16	0.35	0.0083	0.018
	2	0.16	0.34	0.0089	0.020
	3	0.16	0.35	0.0082	0.018
Test Average (n=3)		0.16	0.34	0.0085	0.019
D	1	0.62	1.37	0.016	0.036
	2	0.68	1.51	0.020	0.043
	3	0.82	1.82	0.022	0.048
Test Average (n=3)		0.71	1.56	0.019	0.042
F	1	0.28	0.62	0.0070	0.015
	2	0.32	0.72	0.0072	0.016
	3	0.33	0.72	0.0069	0.015
Test Average (n=3)		0.31	0.69	0.0070	0.015
System Average (n=5)				0.011	0.023

[z] 227 kg (500 lb) equivalent

Figure 14 shows an example of samples recovered from a typical 2nd stage mote 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 15 shows an example of samples recovered from an atypical 2nd stage mote test run with no lint fiber present.

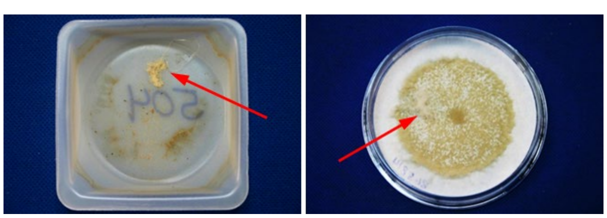

Figure 14. Typical EPA Method 17 filter and sampler head acetone wash from the second stage mote system with lint fibers (indicated by arrows). From left to right: front half wash and filter.

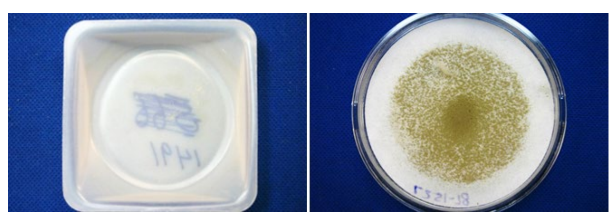

Figure 15. EPA Method 17 filter from the second stage mote system with no lint fiber present. From left to right: front half wash and filter.

SUMMARY

Five cotton gins with 2nd stage mote systems were sampled using EPA Method 17 to collect total particulate emission factor data for cotton gins. Each of the gins had 2nd stage mote system exhausts that were not combined with the 1st stage mote systems. 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 five gins was 29.5 bales/h. The average 2nd stage mote system total particulate emission factor based on the five gins tested (15 total test runs) was 0.011 kg/227-kg bale (0.023 lb/500-lb bale). The gin test average emission rates ranged from 0.16 to 0.71 kg/h (0.34-1.56 lb/h).

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