ENGINEERING AND GINNING

Unloading 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. EPA AP-42 emission factors generally are assigned a rating, from A (excellent) to E (poor), to assess the quality of the data being referenced. Current EPA total particulate emission factor quality ratings for cotton gins are extremely low. Cotton gin data received these low ratings because the data were collected almost exclusively from a single geographical region. The objective of this study was to collect additional total particulate emission factor data for unloading systems from cotton gins located in regions across the cotton belt using EPA-approved stack sampling methodology, Method 17. 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 unloading system exhausts were sampled. The average production rate during testing for the three gins was 24.7 bales/h. The unloading system average total particulate emission factor based on three tests (nine total test runs) was 0.134 kg/227-kg bale (0.296 lb/500-lb bale). This average total particulate emission factor was higher than that currently published in 1996 EPA AP-42, which was 0.13 kg/bale (0.29 lb/bale).

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The unloading system emission rate test averages ranged from 1.56 to 3.93 kg/h (3.43-8.67 lb/h).

U.S. Environmental Protection Agency (EPA) emission factors published in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996b) are assigned a rating that is used to assess the quality of the data being referenced. Ratings can range from A (excellent) to E (poor). Current EPA emission factor quality ratings for total particulate from cotton gins are extremely low. Cotton gin data received these low ratings because they were collected almost exclusively from a single geographical region, far western U.S. (EPA, 1996a). 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 cotton ginning associations across the country, state and federal regulatory agencies, Oklahoma State University, and USDA-Agricultural Research Service (ARS) researchers developed a proposal and sampling plan that was initiated in 2008 to address this need for additional data. This report is part of a series that details cotton gin emissions measured by stack sampling. Each manuscript in the series addresses a specific cotton ginning system. The systems covered in the series include: unloading, 1st stage seed-cotton cleaning, 2nd stage seed-cotton cleaning, 3rd stage seed-cotton cleaning, overflow, 1st stage lint cleaning, 2nd stage lint cleaning, combined lint cleaning, cyclone robber, 1st stage mote, 2nd stage mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser, and master trash. This report focuses on total particulate emissions from unloading systems.

The 1996 EPA AP-42 average total particulate emission factor for the unloading fan was 0.13 kg (0.29 lb) per 217-kg [480-lb] equivalent bale with a range of 0.041 to 0.18 kg (0.090-0.40 lb) per bale (EPA, 1996a, b). This average and range was based on eight 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 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 approximately 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, steadily declining 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 approximately 25 bales per hour across the U.S. cotton belt (Valco et al., 2003, 2006, 2009, 2012).
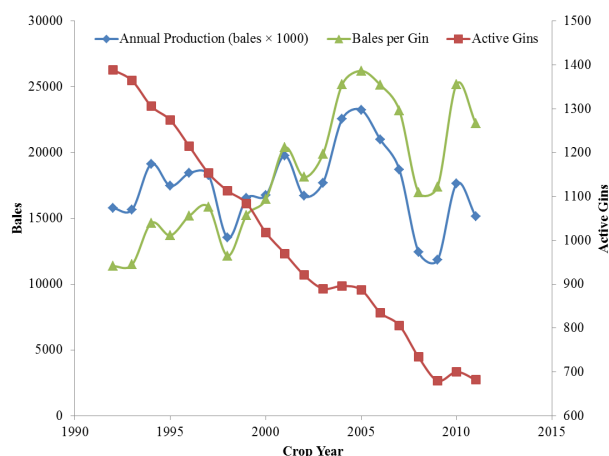

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

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 fiber from the seed. Lint cleaning systems further clean the cotton lint after ginning. The battery condenser and packaging systems combine lint from the lint cleaning systems and compress the lint into dense bales for efficient transport. Ginning systems produce some type of by-products or trash, such as rocks, soil, sticks, hulls, leaf material, and short or tangled immature fiber (motes), as a result of processing the seed-cotton or lint. These streams of by-products must be removed from the machinery and handled by trash collection systems. These trash systems typically further process the by-products (e.g., mote cleaners) and/or consolidate the trash from the gin systems into a hopper or pile for subsequent removal.
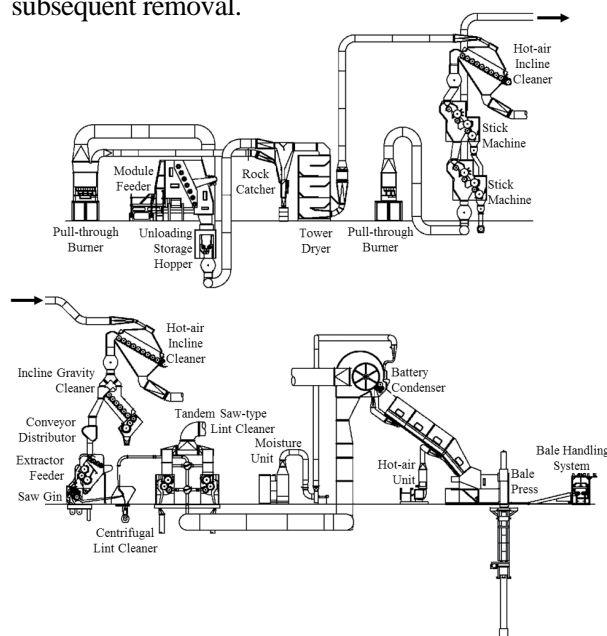

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

The typical unloading system at a cotton gin employs a module feeder, which mechanically breaks apart the module (Fig. 3). The seed-cotton is then mechanically conveyed directly to a feed-control device or

mechanically conveyed to a heated-air suction pick-up, then pneumatically conveyed to an unloading system screened separator where the seed-cotton is removed from the airstream and dropped into a feed-control device. The pneumatic system will flow through a rock and green boll trap to remove these and other heavy objects from the seed-cotton. Very little seed-cotton is transported from the field in cotton trailers; however, when trailers are used, the seed-cotton is pneumatically unloaded via a telescoping suction pipe. The airstream from the unloading system screened separator continues through a centrifugal fan to one or two particulate abatement cyclones. The unloading system might use air heated to 117°C (350°F) at the seed-cotton and air-mixing point to accomplish drying during transport (ASABE, 2007). Based on system configuration, the airstream temperature at the abatement device could range from ambient to approximately 50% of the mixing point temperature. The material handled by the unloading cyclones typically includes soil and small leaves, but also can contain larger material like rocks, sticks, and hulls (Fig. 4). Some unloading systems do not utilize a feed-control device, in which case the module feeder supplies seed-cotton directly into the 1st stage seed-cotton cleaning system via a similar heated-air suction pick-up. These types of unloading systems do not require unloading system cyclones.
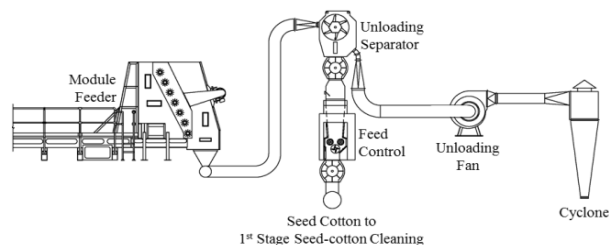

Figure 3. Typical cotton gin unloading system layout (Courtesy Lummus Corporation, Savannah, GA).

Figure 4. Photograph of typical trash captured by the unloading 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 might have the original 1D3D inlet with height of D and width D/8. Also, it has a design inlet velocity of 16.3 ± 2 m/s (3200 ± 400 fpm).

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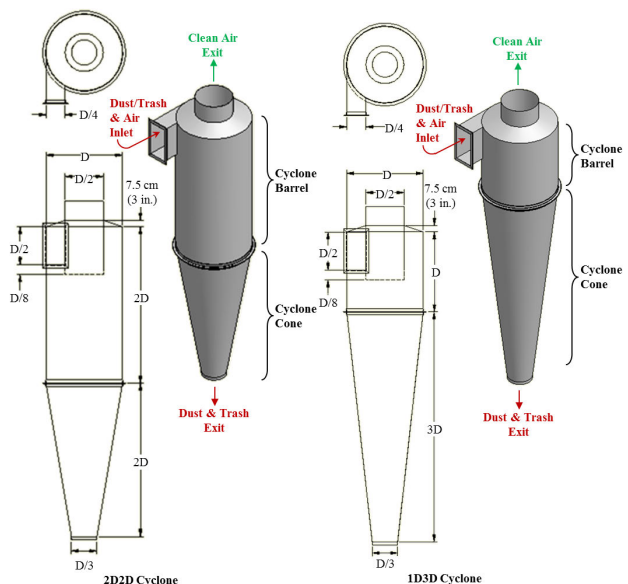

Figure 5. 2D2D and 1D3D cyclone schematics.

METHODS

Two advisory groups were established for this project. The industry group consisted of cotton ginning industry leaders and university and government researchers. The air quality group included members from state and federal regulatory agencies and university and government researchers. Both groups were formed to aid in

project planning, gin selection, data analyses, and reporting. The project plan was described in detail by Buser et al. (2012).

Seven 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 unloading 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 particulate on the filter and the front half wash. Stack gas temperature and moisture content were also measured using EPA Method 17.
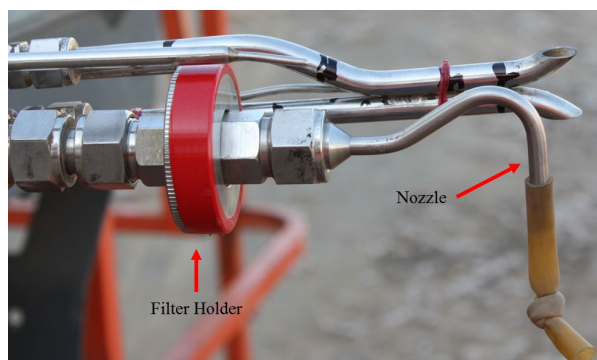

Figure 6. EPA Method 17 total particulate button-hook nozzle and in-stack filter holder photograph.

Only one stack from each unloading system was tested. For systems with multiple stacks, it was assumed that emissions from each stack of the system were equivalent. The overall 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 $\geq$ 99.5%). Filters, wash tubs, and lids were prelabeled and preweighed 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.
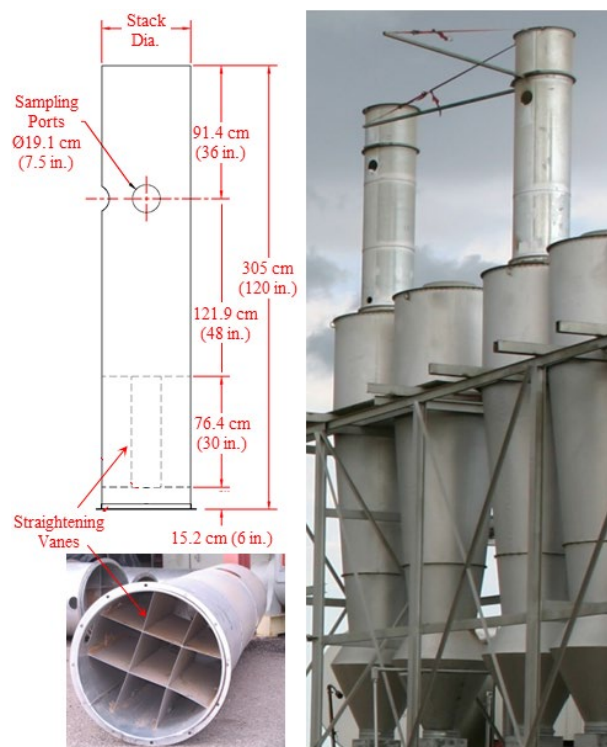
Figure 7. Schematic and photographs of stack extensions with sampling port and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

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 preweighed 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 ASAE Standard S582 (ASABE, 2005).

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber (21 ± 2°C [70 ± 3.6°F]; 35 ± 5% RH) for 48 h prior to gravimetric analyses. Filters were weighed in the environmental chamber on a Mettler MX-5 microbalance (Mettler-Toledo

Inc., Columbus, OH; 1 µg readability and 0.9 µg repeatability) after being passed through an antistatic 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.
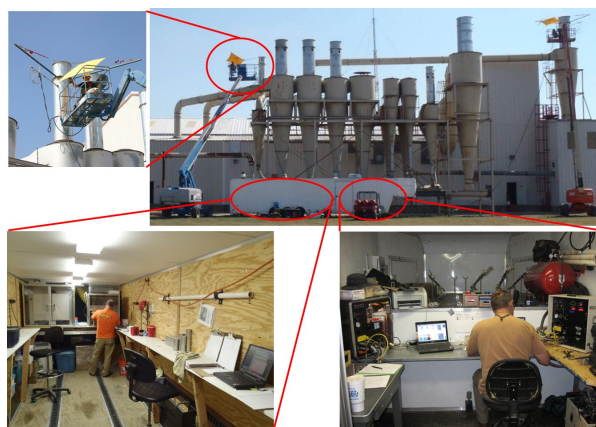

Figure 8. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

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, C, and D) sampled had unloading systems that used pneumatic conveyance and had exhaust airstreams that were not combined with another system. The unloading systems sampled were typical for the industry. Two gins (A and D) had similar system configurations (Fig. 9). The seed-cotton material in a tightly packed module was picked apart by the rotating spiked cylinders of the module feeder and then conveyed pneumatically from the module feeder to the feed-control unit. At

the feed-control unit, the seed-cotton was separated from the conveying air by a screened separator and dropped into the feed control that regulated the flow of seed-cotton to the remainder of the gin plant. The airstream then passed through a fan and exhausted through one or more cyclones. The gin C system was similar to the other two gins, except after the module feeder the material and conveying airstream was split and preceded to two, separate and parallel, feed-control units with separate fans and emissions control cyclones (Fig. 10).

All unloading systems sampled utilized 1D3D cyclones to control emissions (Table 1 and Figs. 5 and 11). All the gins split the system exhaust flow between two cyclones in a dual configuration (side by side as opposed to one behind another). Inlets on all the unloading cyclones were 2D2D type. Expansion chambers were present on unloading cyclones at all gins. All of the cyclone configurations outlined above, if properly designed and maintained, are recommended for controlling cotton gin emissions (Whitelock et al., 2009).
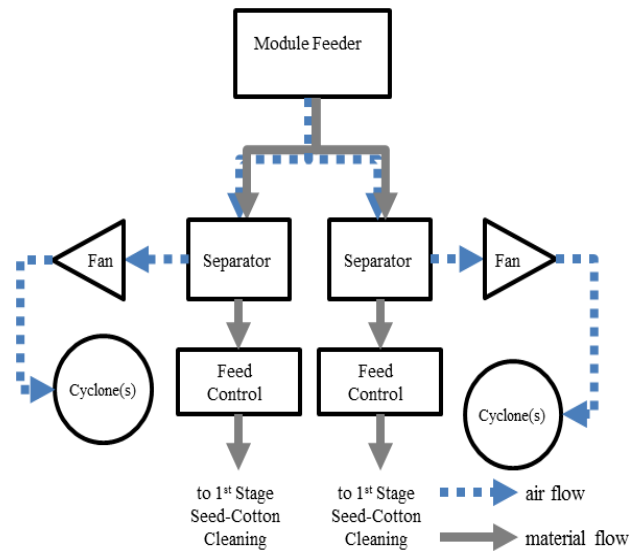

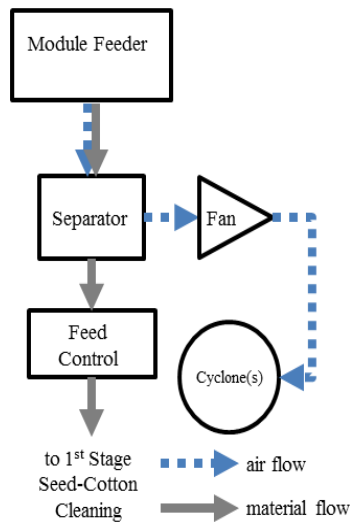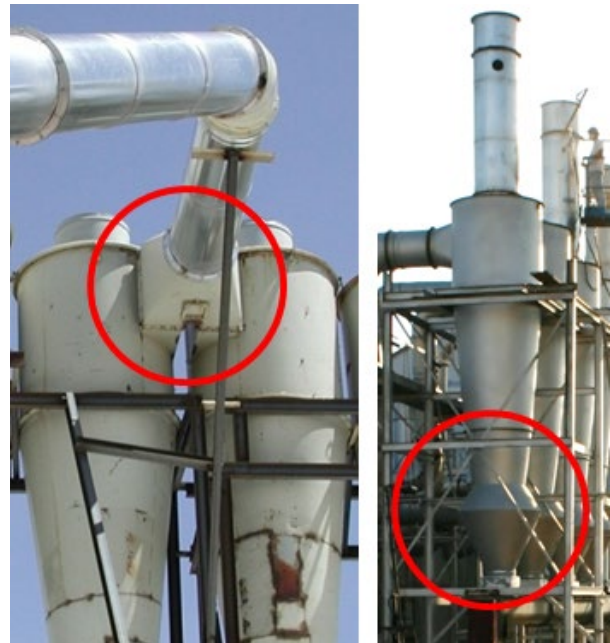Figure 10. Schematic of split stream unloading system (gin C).

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 2D2D inlet and expansion chamber on the cone.

Figure 9. Schematic of single stream unloading system (gins A and D).

Table 1. Abatement device configuration for unloading systems tested.

Gin	Cyclone Type	Inlet Design	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash Exits[z]
A	1D3D	2D2D	1	2	dual	expansion chamber	hopper
C	1D3D	2D2D	2	4	dual	expansion chamber	auger
D	1D3D	2D2D	2	4	dual	expansion chamber	auger

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

RESULTS

Table 2 shows the test parameters for each Method 17 test run for the unloading systems sampled at the three gins. The system average ginning rate was 24.7 bales/h and the test average ginning rate at each gin ranged from 17.3 to 33.6 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 test runs at gin D 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 $100 \pm 10\%$. All tests met the isokinetic criteria (Table 2). The stack gas temperatures ranged from 16 to 24°C (61-75°F) and moisture content ranged from 0.4 to 1.8% w.b.

Total particulate emissions data (emission rates and corresponding emission factors) for the unloading system are shown in Table 3. The system average emission factor for the three gins was 0.134 kg/bale (0.296 lb/bale). The test average emission factors ranged from 0.072 to 0.227 kg (0.159-0.500 lb) per bale. The average unloading system total particulate emission factor for this project was similar to that published in the current 1996 EPA AP-42, which is 0.13 kg/bale (0.29 lb/bale) (EPA, 1996a, b). The range of test average total particulate emission factors determined for this project and the range of AP-42 emission factor data range overlapped. The test average emission rates ranged from 1.56 to 3.93 kg/h (3.43-8.67 lb/h).

Figure 12 shows an example of samples recovered from a typical unloading 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 (Fig. 13) or in the front half wash, which was included in the total particulate emissions.
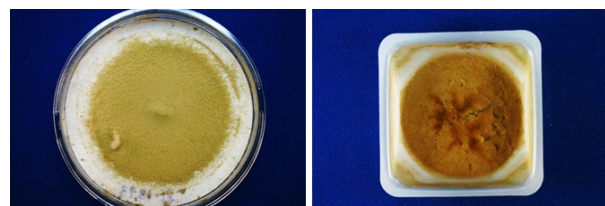

Figure 12. Typical EPA Method 17 filter and sampler head acetone wash from the unloading system. From left to right: front half wash and filter.
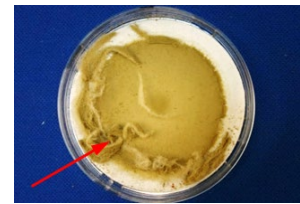

Figure 13. EPA Method 17 filter from the unloading system with lint fibers (indicated by arrows).

Table 2. Cotton gin production data and stack sampling performance metrics for the unloading systems.

Gin	Test Run	Ginning Rate	Cyclone Inlet Velocity		Isokinetic Sampling	Stack Gas		
						Moisture Content	Temperature	
		bales/h[z]	m/s	fpm	%	% w.b.	°C	°F
A	1	25.5	16.5	3250	100	0.4	21	69
	2	25.4	16.6	3262	92	0.5	19	66
	3	18.4	16.7	3294	104	1.5	21	70
Test Average		23.1	16.6	3268				
C	1	16.1	17.4	3424	95	0.7	19	66
	2	17.4	17.6	3459	95	1.1	20	69
	3	18.3	17.0	3347	97	1.8	24	75
Test Average		17.3	17.3	3410				
D	1	32.2	13.9	2738	102	1.3	16	61
	2	34.2	13.5	2657	99	1.7	18	64
	3	34.4	13.8	2719	101	1.8	21	70
Test Average		33.6	13.7	2705				
System Average		24.7	15.9	3128				

[z] 227 kg (500 lb) equivalent bales

Table 3. Total particulate emissions data for the unloading systems.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	1.31	2.89	0.051	0.113
	2	1.17	2.57	0.046	0.101
	3	2.20	4.84	0.119	0.263
Test Average (n=3)		1.56	3.43	0.072	0.159
C	1	2.90	6.38	0.180	0.396
	2	4.76	10.50	0.274	0.604
	3	4.14	9.14	0.226	0.499
Test Average (n=3)		3.93	8.67	0.227	0.500
D	1	3.51	7.74	0.109	0.240
	2	3.19	7.03	0.093	0.206
	3	3.79	8.36	0.110	0.243
Test Average (n=3)		3.50	7.71	0.104	0.230
System Average (n=3)				0.134	0.296

[z] 227 kg (500 lb) equivalent bales

SUMMARY

Three cotton gins with unloading systems were sampled using EPA Method 17 to collect additional data to improve the EPA AP-42 total particulate emission factor quality ratings 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. The average production rate during testing for the three gins was 24.7 bales/h. The average unloading system total particulate emission factor based on the three gins tested (nine total test runs) was 0.134 kg/bale (0.296 lb/bale). The average unloading system total particulate emission factor for this project was similar to that currently published in the 1996 EPA AP-42, which is 0.13 kg/bale (0.29 lb/bale) (EPA, 1996 a, b). The gin test average emission rates ranged from 1.56 to 3.93 kg/h (3.43-8.67 lb/h).

ACKNOWLEDGMENTS

DISCLAIMER

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 Air Pollution Study Agency, or its Policy Committee, their employees or their members. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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