The Society for engineering in agricultural, food, and biological systems

Paper Number: 034113
An ASAE Meeting Presentation

Characteristic Particle Size Distribution for Cotton Gins: Based on the 1996 AP-42 Emission Factors

Michael D. Buser, Agricultural Engineer

Cotton Production and Processing Research Unit,
USDA/ARS
Lubbock, TX

Calvin B. Parnell, Jr., Regents Professor

Bryan W. Shaw, Associate Professor

Ronald E. Lacey, Associate Professor

Department of Biological and Agricultural Engineering,
Texas A&M University,
College Station, TX

Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003

Abstract. *Agricultural operations across the United States are encountering difficulties in complying with the current air pollution regulations for particulate matter (PM). Cotton gins are most frequently regulated based on results obtained from dispersion modeling that utilize emission rates based on emission factors from EPA's 1996 AP-42 or emission rates derived from source sampling. PM_{10} emission factors are typically determined from source sampling based on EPA's Method 201a sampling protocol. Method 201a utilizes a cyclone in the sampling system to remove the larger particles and allow the smaller particles to penetrate to the filter. EPA has published limited information documenting the performance characteristics of the cyclones used in Method 201a. Recent research has shown that ambient PM_{10} samplers can over-estimate the true PM_{10} in the ambient air when the sampler is exposed to dust with a mass median diameter larger than 10 μm.*

The purpose of this manuscript is to explore the potential impacts associated with determining PM_{10} emission values for cotton gin exhausts using the EPA's Method 201a. Two theoretical methods were introduced to estimate the true PM_{10} emitted from process streams associated with cotton gins. The first method was based on defining particle size distributions for each individual process stream exhaust. The second method expanded the first method by defining an average weighted particle size distribution. Estimates from the first and second methods showed that the total true PM_{10} emission factors were about 28 and 26% lower than EPA's 1996 AP-42 total PM_{10} emission factor, respectively. The percent of true PM_{10}, based on total PM_{10} and TSP emission factors, determined by methods 1 and 2 were 28 and 29%, respectively; whereas the current EPA 1996 AP-42 defined estimate of the percent PM_{10} is 39%. Therefore, when cotton gins are regulated based on PM_{10} emission factors from AP-42 or emission factors derived from EPA's Method 201a source sampling procedures the cotton gins are being force to comply with more stringent PM regulations than urban type sources. The bottom line is that regulatory agencies are using sampling methods developed to regulate urban sources to regulate agricultural sources, and these methods introduce substantial errors when the mass median diameter of the dust being emitted is larger than 10 μm.

Keywords. Air Pollution, environmental impact, particle size distribution, PM, PM10, samplers, sampling, sampler performance, emission factor.

Introduction

The Federal Clean Air Act (FCAA) of 1960 and subsequent amendments established national goals for air quality and incorporated the use of standards for the control of pollutants in the environment. The 1970 FCAA Amendments (FCAAA) provided the authority to create the Environmental Protection Agency (EPA) and required the EPA to establish National Ambient Air Quality Standards (NAAQS) (U.S. Environmental Protection Agency, 1996b). The NAAQS are composed of primary (based on protecting against adverse health effects of listed criteria pollutants among sensitive population groups) and secondary standards (based on protecting public welfare e.g., impacts on vegetation, crops, ecosystems, visibility, climate, man-made materials, etc). In 1971, EPA promulgated the primary and secondary NAAQS, as the maximum concentrations of selected pollutants (criteria pollutants) that, if exceeded, would lead to unacceptable air quality (Federal Register, 1971). The NAAQS for particulate matter (PM) was established and total suspended particulate (TSP) was defined as the criteria pollutant. The FCAAA of 1977 required EPA to review and revise the ambient air quality standards every five years to ensure that the standards met all criteria based on the latest scientific developments (U.S. Environmental Protection Agency, 1996b). In 1987 EPA modified the PM standard by replacing TSP with a new criteria pollutant that accounts for particles with an aerodynamic equivalent diameter (AED) less than or equal to a nominal 10 μm (PM_{10}) (Federal Register, 1987). On July 16, 1997, the EPA promulgated additional NAAQS for PM. This update incorporated an additional criteria pollutant for the ambient air standards that would account for particles with an AED less than or equal to a nominal 2.5 μm ($PM_{2.5}$) (Cooper and Alley, 1994).

The NAAQS for PM_{10} are the concentration limits set by EPA that should not be exceeded (U. S. Environmental Protection Agency, 2000a). The regional or area consequences for multiple exceedances of the NAAQS result in an area being designated as nonattainment with a corresponding reduction in the permit allowable emission rates for all sources of PM in the area. The source-specific consequence of an exceedance of the NAAQS at the property line is the State Air Pollution Regulatory Agency (SAPRA) denying an operating permit. The current PM_{10} primary 24-hour NAAQS is 150 micrograms per actual cubic meter (μg/acm) (U. S. Environmental Protection Agency, 2000a). The secondary NAAQS for PM_{10} is set at the same level as the respective primary NAAQS.

Particle Size Distributions

The distribution of particles with respect to size is perhaps the most important physical parameter governing their behavior. Hinds (1982) indicated that most aerosols in the ambient air are polydisperse and that the lognormal distribution “is the most common distribution used for characterizing the particle sizes associated with the aerosol”. The significance of using a lognormal distribution is that the particle size distribution (PSD) can be described in terms of the mass median diameter (MMD) and the geometric standard deviation (GSD). Three important characteristics of lognormal distributions are: (1) the mode shifts significantly to the left as the GSD increases, (2) the median is not affected by the increase in GSD, and (3) the larger the GSD the more closely the lognormal distribution is to a uniform distribution (Stockham and Fochtman, 1977).

Particle size distributions will vary between environments. For instance, urban dust has an MMD of 5.7 μm and a GSD of 2.25 (U. S. Environmental Protection Agency, 1996b), which is much smaller than dust from rural sources. Agricultural sources are classified as rural sources by the U. S. Environmental Protection Agency (1996a). Agricultural dusts, such as grain dust, have MMD's ranging from 12 to 16 μm and GSD's ranging from 1.8 to 2.2 (Parnell et al., 1986). Cotton gin dusts have MMD's ranging from 18 to 23 μm and GSD's ranging from 1.8 to 2.0 (Wang, 2000). The EPA reference and equivalent methods of sampling ambient PM are mandated in the presence of urban dusts, and not rural dusts. However, either method may be used in determining whether or not a rural source is in compliance with PM regulations.

Sampler Performance Characteristics

Sampler performance is generally described by either a cumulative collection or penetration efficiency curve. The "sharpness of cut" of the sampler pre-separator or the "sharpness on the slope" of the sampler penetration efficiency curve significantly impacts the accuracy of sampler measurements (Hinds, 1982). Three terms are often used to describe the sharpness of the penetration curve. These terms are ideal, true, and sampler cut. An ideal cut for an ambient air sampler corresponds to the penetration curves provided in 40CFR53 (U. S. Environmental Protection Agency, 2000b). Currently, EPA does not provide data representing an ideal cut for stack samplers. A true penetration curve can be described as a step function; in other words, all the particles less than or equal to the size of interest are captured on the filter, and all particles greater than the particle size of interest are captured by the pre-separator. A sampler cut refers to the actual penetration curve associated with a particular sampler. A sampler cut is defined by a sampler's performance characteristics (i.e. d_{50} or cut-point and slope). With a sampler cut, a portion of the PM less than the size of interest will not be collected on the filter and a portion of the PM greater than the size of interest will be collected on the filter (Copper and Alley, 1994).

A sampler's pre-separator collection efficiency curve is most commonly represented by a lognormal distribution, which is characterized by the d_{50} (also referred to as cut-point) and slope of the collection efficiency curve (Hinds, 1982). The cut-point is the particle size where the pre-separator captures 50% of the PM and 50% of the PM penetrates to the filter. The slope is calculated as the ratio of the particle sizes corresponding to cumulative collection efficiencies of 84.1% and 50% ($d_{84.1}/d_{50}$) or 50% and 15.9% ($d_{50}/d_{15.9}$) (Cooper and Alley, 1994). Collection efficiency curves are usually assumed as constant and independent of particle size; in other words, it is assumed that a significant loading of large particles does not affect the pre-separators collection efficiency. Therefore, concentration data used to generate a sampler's pre-separator collection efficiency curve is typically determined by conducting an array of tests over several mono-disperse particle sizes using known concentrations (U.S. Environmental Protection Agency, 2000b). The concentration data from each test is used to determine the collection efficiency, associated with each particle size. A smooth lognormal curve is fit to the calculated pre-separator collection efficiencies and the sampler performance characteristics (d_{50} and slope) are determined from the fitted curve.

Stack samplers approved by EPA are designed quite differently than EPA approved ambient air samplers, as one would expect. However, the details provided by EPA regarding PM_{10} stack samplers are very limited in comparison to ambient air samplers. In addition, one would assume that EPA would impose the same sampler performance standards on stack samplers as those for the ambient air samplers. The limited information provided by EPA includes: cut-points and an acceptable collection efficiency envelope for the PM_{10} stack sampler. The d_{50} for the PM_{10} stack samplers is explicitly defined as 10 ± 1 μm (Code of Federal Regulations, 2001). To aid in illustrating the major problem associated with EPA's limited information on the sampler performance characteristics, three theoretical sampler collection efficiency curves were overlaid on EPA's PM_{10} cyclone efficiency envelope, shown in Figure 1. Essentially, the slope associated with the EPA approved PM_{10} stack samplers can range from 1.0 to 1.87, 1.90, and 1.76 for cut-points of 9, 10, and 11 μm, respectively. These sampler performance characteristics are much broader than those for the ambient air samplers and will result in a greater degree of uncertainty in the sampler measurements.

Sampler Errors: Interaction of Particle Size and Sampler Performance Characteristics

Buser et al. (2001, 2002, and 2003) defined ambient air sampler errors due to the interaction of particle size and sampler performance characteristics. Figure 2 illustrates the interaction associated with a uniformly distributed PSD and EPA's optimum ambient PM_{10} sampler performance characteristics (i.e. d_{50} = 10 μm; slope = 1.5). The two errors associated with the interaction are highlighted and labeled as mass 1 and mass 2. Mass 1 refers to an under-sampling error, while mass 2 corresponds to an over-sampling error. A common assumption made in the regulatory community to circumvent the problem associated with the two errors is that the mass of particles less than 10 μm and also captured by the pre-separator (mass 1) is equal to the mass of particles greater than 10 μm and also captured on the filter (mass 2). This assumption is valid when the density function of the PSD of the dust in the air being sampled is represented by a uniform distribution, i.e. mass 1 equals mass 2.

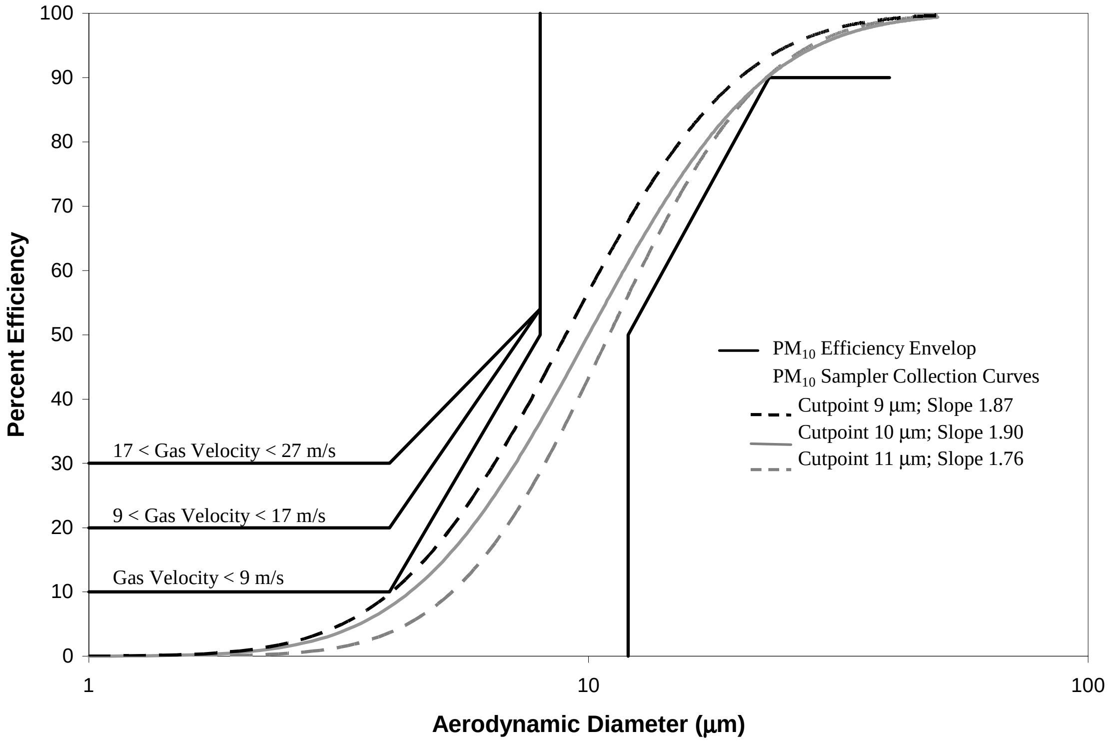

Figure 1. Method 201a PM_{10} cyclone efficiency envelope and theoretical PM_{10} cyclone collection efficiency curves.

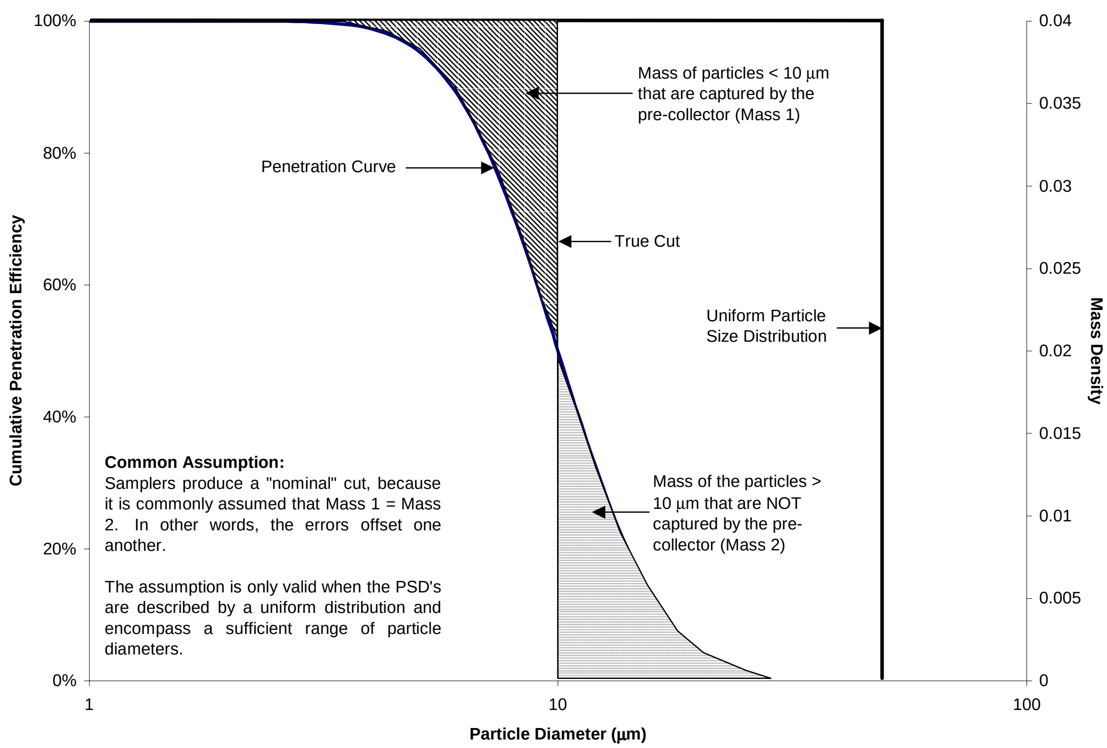

Figure 2. PM_{10} sampler nominal cut for a uniform PSD.

EPA's performance criteria for the PM_{10} stack samplers are extremely limited in comparison to their ambient air samplers. For example, EPA does not provide ideal sampler concentrations for the PM_{10} stack samplers; the only information available from EPA that can be used in describing the penetration efficiency slope of the PM_{10} stack sampler is the efficiency envelope shown in Figure 1. However, the information provided by EPA (i.e. stack sampler d_{50} ranges and the PM_{10} stack sampler efficiency envelope) can be used to estimate the over-sampling that can occur with EPA approved stack samplers. For example, assume that the PM_{10} stack sampler has a d_{50} of 11 µm and a slope of 1.76 (acceptable performance criteria for this type of sampler according to EPA) is sampling dust from an agricultural operation that can be characterized by a MMD of 20 µm and a GSD of 1.5. Based on this scenario, the error relating to the mass of particles greater than 10 µm and deposited on the filter (mass 2) is 11.55 times the error relating to the mass of particles less than 10 µm and captured by the pre-separator, as shown in Figure 3. In other words, the concentration measured by this sampler is 4.5 times the true PM_{10} concentration.

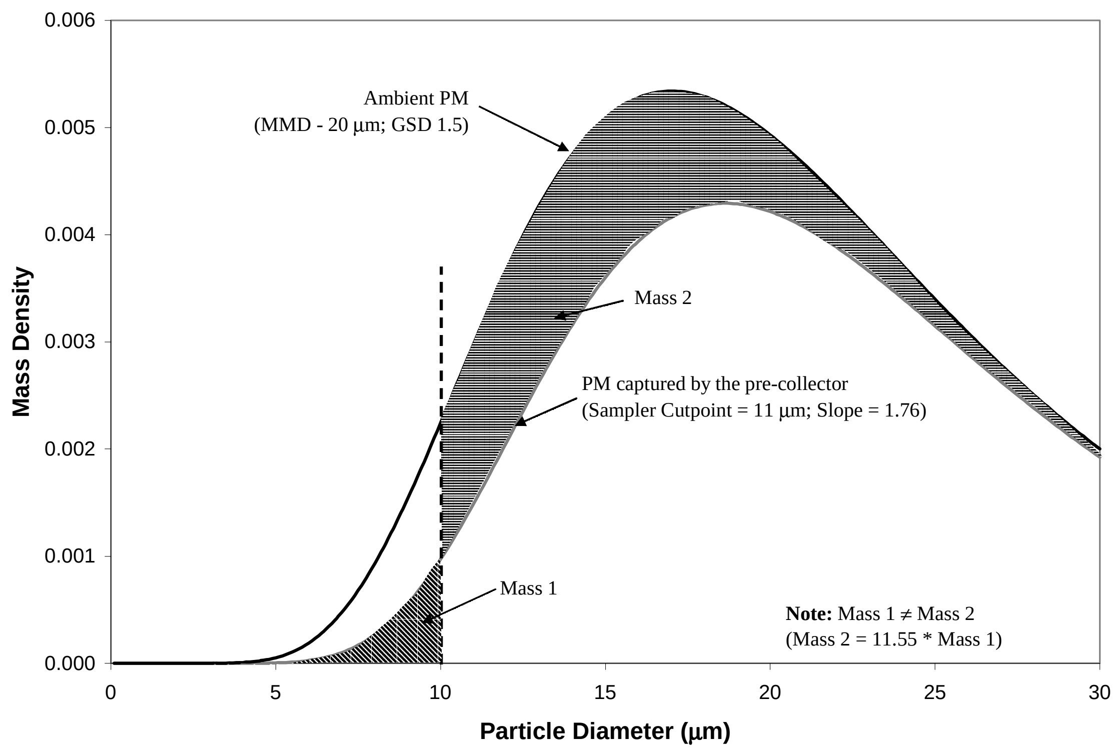

Figure 3. PM_{10} stack sampler nominal cut (sampler d_{50} = 11 µm; slope = 1.76) for a lognormal PSD with a MMD = 20 µm and GSD = 1.5.

Cotton Gins

The number and type of process streams associated with cotton gin systems will vary from gin to gin. A process stream refers to a sequence of one or more process that is followed by an exhaust. A cotton gin material handling system flow diagram is illustrated in Figure 4, which includes the basic process streams found in virtually all gins and optional streams that may or may not be associated with a particular cotton gin. The basic streams include: 1) unloading, either suction or module feeder; 2) 1st stage of seed cotton cleaning; 3) 2nd stage of seed cotton cleaning; 4) distributor/overflow; 5) 1st stage of lint cleaning; 6) 2nd stage of lint cleaning; 7) battery condenser; 8) mote; and 9) trash. Optional process streams that may be incorporated in a particular cotton gin are: 1) 3rd stage of seed cotton cleaning; 2) overflow separator; 3) 3rd stage of lint cleaning; 4) mote cleaning; and 5) cyclone robber.

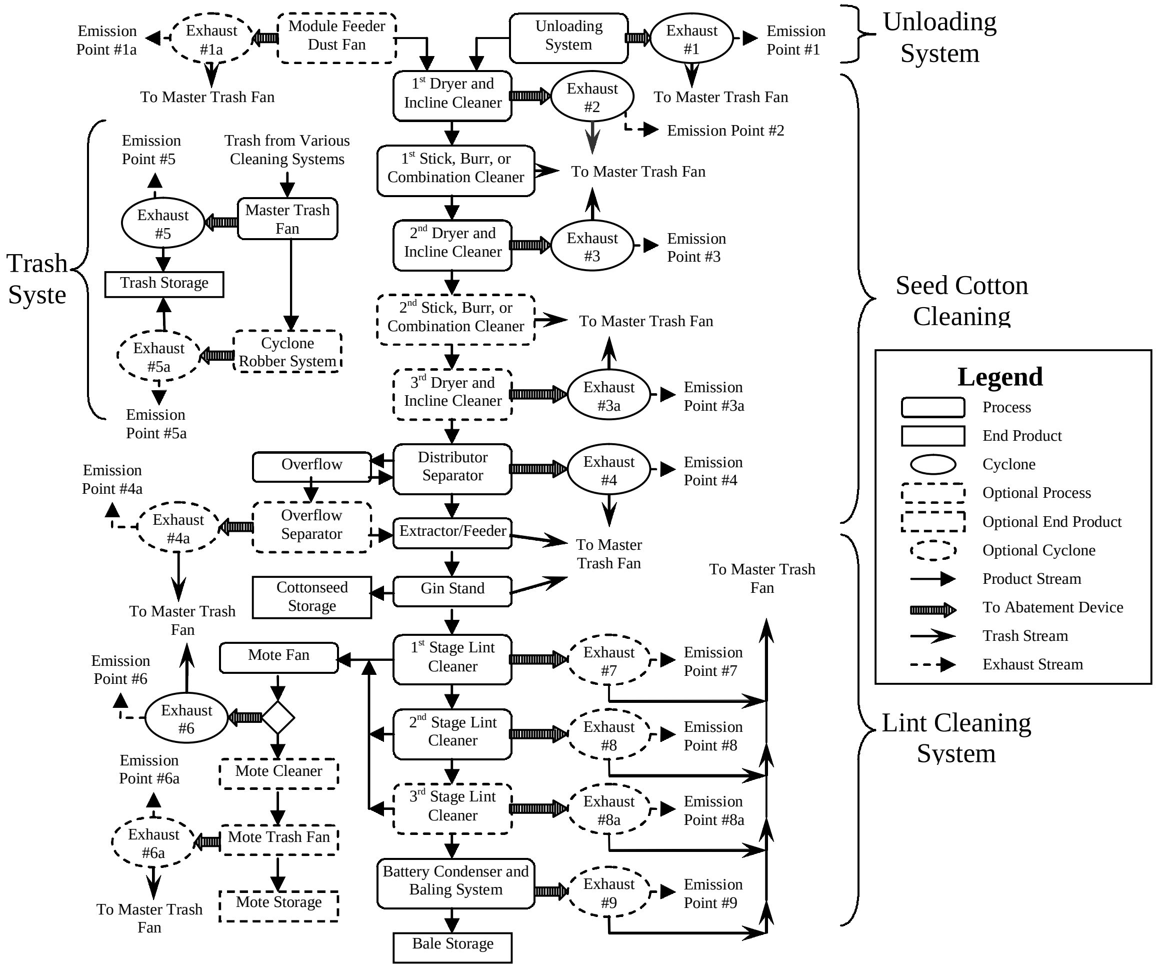

Figure 4. Cotton Gin Material Handling System Flow Diagram.

EPA published emission factors for cotton gins in AP-42 (U.S. EPA, 1987; U.S. EPA, 1996a) should be used as guidelines in the permitting process if actual source sampling data is not available for a particular gin. The 1996 AP-42 TSP and PM_{10} emission factors are listed in Table 1. Within AP-42, EPA provides emission factors for virtually all cotton gin exhausts illustrated in Figure 4. Process stream exhaust emission factors not incorporated (shown as not reported in Table 1) in the 1996 AP-42 document are: 1) TSP and PM_{10} values for the module feeder and overflow separator; 2) PM_{10} values for lint cleaners and battery condensers with covered condenser drums; and 3) individual lint cleaner exhausts.

Table 1. Cotton gin emission factors.

Process Stream	Emission Point	1996 AP-42 Emission Factor TSP, kg/bale (lb/bale)	1996 AP-42 Emission Factor PM_{10}, kg/bale (lb/bale)	PM_{10} to TSP Ratio (%)
Unloading	1	0.132 (0.29)	0.054 (0.12)	41.4
Module Feeder	1a	*Not Reported*	*Not Reported*	
1st Stage Seed Cotton Cleaning	2	0.163 (0.36)	0.054 (0.12)	33.3
2nd Stage Seed Cotton Cleaning	3	0.109 (0.24)	0.042 (0.093)	38.8
3rd Stage Seed Cotton Cleaning	3a	0.043 (0.095)	0.015 (0.033)	34.7
Distributor	4	0.032 (0.071)	0.012 (0.026)	36.6
Overflow	4a	*Not Reported*	*Not Reported*	
Trash	5	0.245 (0.54)	0.034 (0.074)	13.7
Cyclone Robber	5a	0.082 (0.18)	0.024 (0.052)	28.9
Mote	6	0.127 (0.28)	0.059 (0.13)	46.4
Mote Trash	6a	0.035 (0.077)	0.010 (0.021)	27.3
1st Stage Lint Cleaning	7			
(Covered Condenser Drum)				
(Cyclone)		*1st and 2nd Stages Combined*		
2nd Stage Lint Cleaning	8	0.499 (1.1)	*Not Reported*	
(Covered Condenser Drum)		0.263 (0.58)	0.109 (0.24)	41.4
(Cyclone)				
3rd Stage Lint Cleaning	8a			
(Covered Condenser Drum)		*Not Reported*	*Not Reported*	
(Cyclone)		*Not Reported*	*Not Reported*	
Battery Condenser	9			
(Covered Condenser Drum)		0.077 (0.17)	*Not Reported*	
(Cyclone)		0.018 (0.039)	0.006 (0.014)	35.9

The purpose of this manuscript is to determine the PSD characteristics associated with cotton gin exhausts based on the 1996 AP-42 emission factors and EPA's Method 201a sampler performance characteristics. These PSD characteristics will be used to determine the true PM_{10} percentage associated with the AP-42 values.

Procedures

The general method used to determine the PSD characteristics associated with cotton gin exhausts based on the 1996 AP-42 emission factors was to systematically solve equations that mathematically describe sampler concentrations through a trial and error process until the calculated value equaled the value corresponding to the 1996 AP-42 ratio of PM_{10} to TSP. Mathcad 2002 was used in the mathematical procedure. In order to solve the equations the following broad assumptions were made:

1. emission factors presented in Table 1 represent typical values that that can be expected from an average cotton gin;
2. the AP-42 emission factors are based on Method 201a sampling data;
3. the Method 201a PM_{10} sampling cyclone performance characteristics are a cut-point of 10 ± 1.0 µm and a slope of 1.5 ± 0.1 and can be described by a lognormal distribution; and
4. the PSD of the dust exiting the exhaust abatement devices can be described by a lognormal distribution.

These assumptions provide the mathematical bases for using the following equations to calculate sampler and true concentrations.

$$f(d_p, MMD, GSD) = \frac{1}{d_p \ln GSD \sqrt{2\pi}} \exp\left[\frac{-(\ln d_p - \ln MMD)^2}{2(\ln GSD)^2}\right] \quad (1)$$

$$P_m(a, d_{50}, slope) = 1 - \int_0^a \left[\frac{1}{d_p \ln(slope)\sqrt{2\pi}} \exp\left[\frac{-(\ln d_p - \ln d_{50})^2}{2(\ln(slope))^2}\right]\right] dd_p \quad (2)$$

$$C_m(MMD, GSD, d_{50}, slope) = \int_0^\infty f(d_p, MMD, GSD) P_m(d_p, d_{50}, slope) dd_p \quad (3)$$

$$C_t(MMD, GSD) = \int_0^{10} f(d_p, MMD, GSD) dd_p \quad (4)$$

where,

$f(d_p,MMD,GSD)$	=	lognormal mass density function;
MMD	=	mass median diameter of the particle size distribution;
GSD	=	geometric standard deviation of the particle size distribution;
d_p	=	incremental particle size;
P_m	=	penetration efficiency of the sampler;
d_{50}	=	50% cutpoint of the sampler performance distribution;
slope	=	slope of the sampler performance distribution;
C_m	=	ratio of sampled PM_{10} to TSP concentrations; and
C_t	=	the ratio of true PM_{10} to TSP concentrations.

There are four unknowns associated with equation 3; therefore, additional assumptions were required. Based on EPA's PM_{10} sampling cyclone cut-point criteria, the d_{50} was assumed to be 11.0 µm. This cutpoint corresponds to the upper limit defined by EPA. Although Figure 1 illustrates that a PM_{10} sampling cyclone can have a slope of 1.76 with a cut-point of 11 µm, a conservative estimate of 1.6 was assumed. This slope corresponds to the criteria EPA set for the PM_{10} ambient air samplers. In order to further simplify this procedure, GSD values of 1.8, 2.0, and 2.2 were assumed. Based on these assumptions, equation 3 was solved through a trial and error process until the calculated value equaled the 1996 AP-42 PM_{10} to TSP ratio. This process was completed for the unloading, 1^{st} and 2^{nd} stages of seed cotton cleaning, distributor/overflow, lint cleaners (1^{st} and 2^{nd} stage combined), mote, battery condenser, and trash process stream exhausts.

The MMD and GSD values obtained from the previous calculations were used to determine true PM_{10} emission factors based on individual process stream exhaust PSD characteristics. Equation 4 was used to calculate the true PM_{10} percentage and this value was multiplied by the corresponding 1996 AP-42 TSP emission factor in order to calculate the true PM_{10} emission factor for each exhaust. This process was completed for MMDs associated with GSDs of 1.8, 2.0, and 2.2 for each process stream exhaust.

In general terms, average PSD characteristics were determined by adding all the PSDs associated with the eight process streams and characterizing the sum a lognormal distribution with an average MMD and GSD. This process incorporated multiplying the 1996 AP-42 individual process stream emission factor by the process steams mass density function and dividing by the total 1996 AP-42 TSP emission factor. This function for each of the process stream exhausts was summed together. This process was performed for particle diameters ranging from 0 to 200 μm in increments 0.01 μm. This series of values was compared to a lognormally distributed PSD described by the average MMD and GSD. The mass density function associated with the average PSD covered the range of 0 to 200 μm in increments of 0.1 μm. The absolute difference between the summed process stream values and the average values were determined for each individual particle size bin. This difference was summed. A trail and error procedure that minimized (close to zero) the summed difference was used to estimate the average MMD and GSD. Equation 4 was used to determine the true PM_{10} percentage associated with the average PSD. This true average PM_{10} percentage was multiplied by each of the 1996 AP-42 TSP emission factors in order to determine the true PM_{10} emission factors based on an average PSD.

Results and Discussion

In performing the trial and error calculations to determine the true percent PM_{10} values, an anomaly was encountered with the lint cleaner emission factor. According to the 1996 AP-42, the TSP emission factor for lint cleaners with covered condenser drums is 1.1 lb/bale, while the PM_{10} emission factor is assumed to be 50% of the TSP value. On the other hand, the TSP value for lint cleaners with high-efficiency cyclones was 0.58 lb/bale, while the PM_{10} emission factor was 0.24 lb/bale, resulting in a percent PM_{10} of 41.4%. The problem associated with the two sets of emission factors is that the percent PM_{10} for lint cleaners with covered condenser drums should be less than that for high-efficiency cyclones. Often in the literature, covered condenser drums and cyclones are assumed to have overall collection efficiencies of 50% and 90%, respectively. However, when these efficiencies are analyzed using lognormal PSD's for the dust and lognormal collection efficiencies for the abatement devices; the percent PM_{10} obtained by a cyclone is higher than the percent PM_{10} obtained from a covered condenser drum. In other words, the mass of PM_{10} and TSP will be higher for covered condenser drums than cyclones, but the percent PM_{10} will be lower for the covered condenser drums than the cyclones. Therefore in this analysis, the 41.4% PM_{10} value will be used for the lint cleaners. In addition, the same anomaly occurs with the battery condenser, so the 35.9% PM_{10} value will be used for the battery condenser.

The MMD and true percent PM_{10} were determined for the unloading, 1^{st} and 2^{nd} stages of seed cotton cleaning, distributor, trash, mote, 1^{st} and 2^{nd} stages of lint cleaning, and for the battery condenser using a trail and error producer based on EPA's TSP and PM_{10} 1996 AP-42 emission factors. In this process, PSD GSD values were assumed to be 1.8, 2.0, and 2.2. The results of the simulation are shown in Table 2. Mass median diameters ranged from 11.8 to 16.3 μm for all exhaust except for the trash process stream exhaust. The MMD associated with the trash exhaust ranged from 25.1 to 29.9 μm. True percent PM_{10} values ranged from 23.8 to 41.3% for all process steam exhaust except for the trash exhaust. The trash exhaust true percent PM_{10} ranged from 5.9 to 8.2%. Overall, the MMD and true percent PM_{10} did vary between process stream exhausts. The effects of varying GSD from 1.8 to 2.2 were minimal in comparison to the effects due to exhaust type. Therefore, MMD and percent true PM_{10} values based on an assumed GSD of 2.0 for all process stream exhausts would be sufficient in describing exhaust PM emission based on the 1996 AP-42 emission factors.

Table 2. Calculated MMD and true percent PM_{10} values for selected cotton gin exhausts.

	GSD = 1.8		GSD = 2.0		GSD = 2.2	
Process Stream	MMD (μm)	PM_{10} (%)	MMD (μm)	PM_{10} (%)	MMD (μm)	PM_{10} (%)
Unloading	13.0	33.2	13.2	34.4	13.4	35.5
1st Stage Seed Cotton Cleaning	15.2	23.8	15.8	25.5	16.3	26.8
2nd Stage Seed Cotton Cleaning	13.7	29.6	14.0	31.4	14.3	32.5
Distributor	14.2	27.5	14.7	28.9	15.1	30.0
Trash	25.1	5.9	27.5	7.2	29.9	8.2
Mote	11.8	38.9	11.9	40.1	11.9	41.3
Lint Cleaning (Covered Condenser Drum)	13.0	33.2	13.2	34.4	13.4	35.5
Battery Condenser (Covered Condenser Drum)	14.4	26.8	14.0	28.3	15.3	29.5

The mass density functions associated with the MMD and GSD values reported in Table 2 were weighted by the process stream exhaust 1996 AP-42 TSP emission factors divided by the total 1996 AP-42 TSP emission factor. These weighted mass density functions for each process stream exhaust were summed and a trial and error procedure was used to determine the weighted average values for MMD, GSD, and true percent PM_{10} for assumed process stream exhaust GSD values of 1.8, 2.0, and 2.2. The results of the simulation are shown in Table 3. The average MMD values ranged from 14.7 to 15.7 μm. The average GSD values ranged from 1.89 to 2.32 and the true percent PM_{10} values ranged from 27.3 to 29.6%. The effects due to the assumed GSD values were minimal, based on the MMD and percent true PM_{10} ranges. Therefore, a weighted average PSD based on an assumed GSD of 2.0 for all process stream exhausts would be sufficient in describing an average weighted PSD for cotton gins.

Table 3. Weighted average values for MMD, GSD, and true percent PM_{10}.

Assumed process stream GSD	MMD (μm)	GSD	True PM_{10} (%)
1.8	14.7	1.89	27.3
2.0	15.2	2.11	28.8
2.2	15.7	2.32	29.6

The percent true PM_{10} values reported in Table 3 were multiplied by the 1996 AP-42 TSP emission factors for the unloading, 1st and 2nd stages of seed cotton cleaning, distributor, trash, mote, 1st and 2nd stages of lint cleaning, and for the battery condenser in order to determine the corresponding true PM_{10} emission factors based on an average weighted PSD. These values are shown in Table 4 along with EPA's 1996 AP-42 PM_{10} emission factors. This table also includes PM_{10} emission factors based on multiplying the true percent PM_{10} values reported in Table 2 by the corresponding EPA

1996 AP-42 TSP emission factors. The PM_{10} emission factors varied by process stream exhaust, as expected. The PM_{10} emission factor variation due to assumed process steam exhaust PSD GSD values of 1.8, 2.0, and 2.2 were minimal for the PM_{10} emission factors based on individual process stream exhaust PSDs. These variations were also minimal for the PM_{10} emission factors based on weighted average PSDs. The PM_{10} emission factors based on true values were lower than EPA's 1996 AP-42 PM_{10} emission factors. For example, the total PM_{10} emission factors for the process stream exhausts previously discussed were 1.2, 0.865, and 0.881 lb/bale based on EPA's 1996 AP-42, individual process stream exhausts with an assumed GSD of 2.0, and average weighted PSDs with an assumed process stream exhaust PSD GSD of 2.0, respectively. The lint cleaner, battery condenser, and trash process stream exhaust PM_{10} emission factors were affected more than the other process steam exhausts in adjusting the EPA 1996 AP-42 emission factors to reflect true PM_{10}. Although, the total true PM_{10} emission factors based on individual process stream exhaust PSDs and average weighted PSDs were similar, the PM_{10} emission factors for the lint cleaners and trash process steam exhausts did vary. For example, the PM_{10} emission factor for the trash stream based on individual process stream PSDs was 0.039 lb/bale and the corresponding emission factor for the weighted average PSD was 0.156 lb/bale.

Table 4. AP-42 PM_{10} emission factors (lb/bale) and calculate factors based on individual process steam exhaust PSDs and weighted average PSDs for various assumed GSDs.

		Individual process stream PSD			Average PSD		
Process Stream	1996 AP-42	GSD 1.8	GSD 2.0	GSD 2.2	GSD 1.8	GSD 2.0	GSD 2.2
Unloading	0.12	0.096	0.100	0.103	0.079	0.084	0.086
1st Stage Seed Cotton Cleaning	0.12	0.086	0.092	0.097	0.098	0.104	0.107
2nd Stage Seed Cotton Cleaning	0.093	0.071	0.075	0.078	0.066	0.069	0.071
Distributor	0.026	0.020	0.021	0.021	0.019	0.021	0.021
Trash	0.074	0.032	0.039	0.045	0.147	0.156	0.160
Mote	0.13	0.109	0.112	0.116	0.076	0.081	0.083
Lint Cleaning (Covered Condenser Drum)	0.55	0.365	0.378	0.391	0.300	0.317	0.326
Battery Condenser (Covered Condenser Drum)	0.085	0.046	0.048	0.050	0.046	0.049	0.050
Total	1.198	0.825	0.865	0.901	0.823	0.881	0.904

The PM_{10} emission factors reported in Table 4 were used in calculating emission rates and concentrations for an example gin. In this example, the gin processes 20 bales/hr and the individual airflow rates are assumed to be those shown in Table 5. This example will be broken down into three sections, PM_{10} emission factors based on EPA AP-42, individual process stream PSDs with a GSD of 2.0, and average weighted PSD based on individual process stream exhaust PSD GSD's of 2.0. Calculated emission rates and concentrations for the three scenarios are shown in Tables 5, 6, and 7, respectively. Also included in these tables are strategies for addressing compliance related issues based on addressing exhausts with the highest rates or concentrations. For the scenario using AP-42 emission factors, it is recommended that emissions from the 1st stage of lint cleaning be addressed first if the strategy is based on emission rates and the mote system if the strategy is based on emission concentrations. Emission rates and concentrations were higher for values based on EPA's AP-42 PM_{10} emission factors as compared to the values based on true PM_{10} emission factors, as expected. The results of comparing the two true PM_{10} methods are relatively similar except for the values associated with the trash process stream exhaust. As previously discussed, the PM_{10} values for the trash process stream based on an average weighted PSD are larger than those associated with the individual process stream PSDs.

Table 5. Total air flow rates and PM_{10} emission rates and concentrations based on AP-42 PM_{10} emission factors for an example 20 bale per hour gin.

Process Stream	Estimated Air Flow (cfm)	Emission Factor (lb/bale)	Emission Rate (lb/hr)	Emission Conc. (mg/m^3)	Emission Rate Strategy	Emission Conc. Strategy
Unloading	14,897	0.12	2.40	43	3	
1st Stage Seed Cotton Cleaning	14,897	0.12	2.40	43	3	
2nd Stage Seed Cotton Cleaning	14,153	0.093	1.86	35		
Distributor	13,408	0.026	0.52	10		
Trash	3,119	0.074	1.48	127		2
Mote	3,119	0.13	2.60	223	2	1
Lint Cleaning (Covered Condenser Drum)	42,000	0.55	11.00	70	1	3
Battery Condenser (Covered Condenser Drum)	21,000	0.085	1.70	22		
Total	126,593	1.198	23.96	572		

Table 6. Total air flow rates and PM_{10} emission rates and concentrations based on PM_{10} emission factors from theoretical process stream exhaust PSDs for an example 20 bale per hour gin. PSD corresponds to process steam exhausts GSDs equal to 2.0.

Process Stream	Estimated Air Flow (cfm)	Emission Factor (lb/bale)	Emission Rate (lb/hr)	Emission Conc. (mg/m^3)	Emission Rate Strategy	Emission Conc. Strategy
Unloading	14,897	0.100	2.00	36	3	
1st Stage Seed Cotton Cleaning	14,897	0.092	1.84	33		
2nd Stage Seed Cotton Cleaning	14,153	0.075	1.50	28		
Distributor	13,408	0.021	0.42	8		
Trash	3,119	0.039	0.78	67		2
Mote	3,119	0.112	2.24	192	2	1
Lint Cleaning (Covered Condenser Drum)	42,000	0.378	7.56	48	1	3
Battery Condenser (Covered Condenser Drum)	21,000	0.048	0.96	12		
Total	126,593	0.865	17.30	424		

Table 6. Total air flow rates and PM_{10} emission rates and concentrations based on PM_{10} emission factors from the theoretical weighted average PSD for an example 20 bale per hour gin. The average weighted PSD corresponds to a MMD of 15.2 μm and a GSD of 2.0.

Process Stream	Estimated Air Flow (cfm)	Emission Factor (lb/bale)	Emission Rate (lb/hr)	Emission Conc. (mg/m^3)	Emission Rate Strategy	Emission Conc. Strategy
Unloading	14,897	0.084	1.68	30		
1st Stage Seed Cotton Cleaning	14,897	0.104	2.08	37	3	
2nd Stage Seed Cotton Cleaning	14,153	0.069	1.38	26		
Distributor	13,408	0.021	0.42	8		
Trash	3,119	0.156	3.12	267	2	1
Mote	3,119	0.081	1.62	139		2
Lint Cleaning (Covered Condenser Drum)	42,000	0.317	6.34	40	1	3
Battery Condenser (Covered Condenser Drum)	21,000	0.049	0.98	12		
Total	126,593	0.881	17.62	560		

Conclusions

True PM_{10} emission factors were estimated based on EPA's 1996 AP-42 emission factors and based on individual process stream exhaust PSDs and weighted average PSD. MMDs for individual process stream exhausts, based on AP-42 emission factors, were greater than 10 μm for all exhausts, resulting in true PM_{10} emission factors that were lower than the factor defined by EPA. The total PM_{10} emission factor based on individual process stream exhaust PSDs was 0.881 lb/bale as compared to 1.2 lb/bale for the 1996 AP-42. The individual process stream exhaust PSDs were weighted by EPA's TSP emission factors and summed in a process aimed at defining a characteristic PSD for cotton gins. Based on an assumed PSD GSD of 2.0, the weighted average PSD was characterized by a MMD of 15.2 μm and a GSD of 2.11. This weighted average PSD resulted in a percent PM_{10} value of 28.8 %, corresponding to a total PM_{10} emission factor of 0.881 lb/bale for an assumed individual process stream exhaust PSD GSD of 2.0.

A generalized PSD describing all cotton gin exhausts would be an ideal solution in addressing the issue of PM_{10} stack sampling errors. This PSD could be used to determine a percent of true PM_{10}, which could be multiplied by TSP emission factors, rates, or concentrations to determine the corresponding true PM_{10} values. The generalized PSD determined in this manuscript appears to be a relatively good fit for all exhausts except for trash process stream exhaust. The trash process stream exhaust true percent PM_{10} was determined to be approximately 7% as compared to 28.8% for the generalized PSD. Therefore, a generalized cotton gin PSD may be appropriate for rough estimates of true PM_{10}; however, true PM_{10} estimates based on individual process stream exhaust PSDs would be more appropriate.

Disclaimer

Mention of a trade name, propriety product or specific equipment does not constitute a guarantee or warranty by the United States Department of Agriculture and does not imply approval of a product to the exclusion of others that may be suitable.

References

Buser, M. D., C.B. Parnell, Jr., R.E. Lacy, and B.W. Shaw. 2001. Inherent biases of PM_{10} and $PM_{2.5}$ samplers based on the interaction of particle size and sampler performance characteristics. Paper No. 01-1167 presented at the 2001 ASAE Annual International Meeting in Sacramento, CA, St. Joseph, MI.

Buser, M. D., C. B. Parnell, Jr., B. W. Shaw and R. E. Lacey. 2002. PM_{10} sampler errors due to interaction of particle size and sampler performance characteristics. Proceedings of the 2002 Beltwide Cotton Production Conferences. National Cotton Council. Memphis, TN.

Buser, M. B., C. B. Parnell, Jr., B. W. Shaw and R. E. Lacey. 2003. $PM_{2.5}$ sampler errors due to interaction of particle size and sampler performance characteristics. Proceedings of the 2003 Beltwide Cotton Production Conferences. National Cotton Council. Memphis, TN.

Code of Federal Regulations, Title 40, Part 51, Appendix M. 2001. Recommended test method for State Implementation Plans. Office of Federal Register, Washington, D. C.

Cooper, C. D. and F. C. Alley. 1994. *Air Pollution Control, A Design Approach.* Prospect Heights, IL. Waveland Press, Inc.

Federal Register. 1971. National primary and secondary ambient air quality standard. F.R. (April 30), 36:8186-8201.

Federal Register. 1987. Revisions to the ambient air quality standards for particulate matter. F.R. (July 1), 52:24, 634-42, 669.

Hinds, W. C. 1982. *Aerosol Technology – Properties, Behavior, and Measurement of Airborne Particles*, 1st ed. New York, NY. John Wiley & Sons, Inc.

Parnell, C. B., Jr., D. D. Jones, R. D. Rutherford, and K. J. Goforth. 1986. Physical properties of five grain dust types. Environmental Health Perspectives. 66:183-188.

Stockham, J. D., and E. G. Fochtman. 1977. *Particle Size Analysis*. Ann Arbor, MI. Ann Arbor Science Publishers, Inc.

U. S. EPA. 1987. Compilation of air pollution emission factors. In AP-42, Section 6.3, Cotton Ginning, 6.3-1-6. Washington, D.C: U.S. EPA.

U. S. EPA. 1996a. Emission Factors. In AP-42, Section 9.7 Cotton Ginning, 9.7-1-9. Washington, D. C.: U. S. EPA.

U. S. Environmental Protection Agency. 1996b . Air quality criteria for particulate matter. Research Triangle Park, NC: Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office; EPA report no. EPA-600/P-95/001aF. Available from: NTIS, Springfield, VA; PB96-168232.

U. S. Environmental Protection Agency. 2000a. 40CFR Part 50 National Ambient Air Quality Standards for Particulate Matter; Final Rule. Federal Register Vol. 65, No. 247.

U. S. Environmental Protection Agency. 2000b. 40CFR Part 53 National Ambient Air Quality Standards for Particulate Matter; Final Rule. Federal Register Vol. 65, No. 249.

Wang, L. 2000. A New Engineering Approach to Cyclone Design for Cotton Gins. M. S. thesis, Agricultural Engineering Dept., Texas A&M University, College Station.