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CHARACTERIZATION OF DUSTS EMITTED BY COTTON GINS IN TERMS OF TRUE PM_{10}

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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 factors from EPA's 1996 AP-42 or emission factors 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 documented the performance characteristics of the cyclones used in Method 201a, which are similar to the performance characteristics of an ambient PM_{10} sampler. 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 the 10 process streams associated with a standard cotton gin. Estimates from the first and second methods showed that the true PM_{10} was about 38 and 63% lower than that obtain by PM_{10} source sampling. This corresponds to estimates of the true PM_{10} percent of 28 and 24% for methods 1 and 2, respectively. Whereas the current estimate of the true PM_{10} percent is 39%, as defined in EPA's 1996 AP-42. Therefore, when cotton gins are regulated based on PM_{10} emission factors from AP-42 or emission factors derived from source sampling based on EPA's Method 201a they 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.

Introduction

State Air Pollution Regulatory Agencies (SAPRA) regulate the air pollution associated with cotton gins. SAPRA permit engineers are required to perform in-depth analysis of cotton gin emissions. The goal of the SAPRA permit engineer is to protect the public. The permit approved by the SAPRA permit engineer specifies the allowable emission rate for the facility. Consulting engineers working with cotton ginners and permit engineers must develop air pollution abatement systems that comply with SAPRA regulations while minimizing costs.

Numerous instances of inappropriate regulatory actions in a number of different states have been reported. These actions came to the attention of the American Society for engineering in agricultural, food, and biological system's (ASAE) PM50 Cotton Engineering Committee in 1998. The committee perceived that these problems were due to a lack of understanding of how to properly utilize cotton gin emission factors in determining emission parameters and that a voluntary standard should be developed. A proposed engineering practice standard was developed to define the operations of a cotton gin with engineering data that could be used by both consulting and permit engineers so that cotton gins could be appropriately regulated. Buser et al. (2001a) presented the proposed standard and illustrated how to apply the standard to a gin with more or fewer process streams than the standard gin.

The primary regulated pollutant emitted by cotton gins is particulate matter (PM) less than or equal to 10 micrometers aerodynamic equivalent diameter (AED), referred to as PM_{10}. In some states, emissions of total suspended particulate matter (TSP) are regulated. Buser et al. (2001a) and the proposed ASAE engineering practice standard focus primarily on TSP. These two documents do state that in order to determine in the PM_{10} emission rates and concentrations, the respective TSP values should be multiplied by 0.39. This implies that 39% of the TSP emitted from a cotton gin is PM_{10}.

The 39% was derived from the 1996 AP-42 total TSP and PM_{10} emission factors for cotton gins with the following process streams: unloading fan, 1st and 2nd stages of seed cotton cleaning, overflow, lint cleaners, motes, battery condenser, and master trash. The individual emission factors and corresponding PM_{10} percentages for each of these process streams are

shown in Table 1. According to the EPA's Emission Factor Documentation for Cotton Ginning (EPA, 1996), the PM_{10} emission factors were primarily determined by the California Air Resources Board's (CARB) Method 501.

The CARB's Method 501 is similar in function to EPA's Method 201a (40CFR51, Alp. M). Method 201a utilizes a cyclone in the sampling system to collect the larger particles and allow the smaller particles to penetrate to a filter. According to the EPA guidelines for Method 201a, the cyclones performance characteristics are defined as a d_{50} equal to 10.0 ± 1.0 μm and a slope of 1.5 ± 0.1. These methods are used to determine the emission concentrations associated with individual process stream exhaust. The emission concentrations are then used with the respective airflow and ginning rates to determine PM_{10} emission factors. The use of these sampling methods, that utilize cyclones with performance characteristics similar to those of an ambient PM_{10} sampler, leads to questions as to whether the resulting PM_{10} emission values are over estimated based on work reported by Buser et al. (2001b).

Buser et al. (2001b) suggests that an ambient PM_{10} sampler could over estimate the PM_{10} ambient air concentration by 243%. This estimate is based on the assumption that dust in the ambient air can be described by a lognormal particle size distribution (PSD) with a mass median diameter (MMD) of 20 μm and a geometric standard deviation (GSD) of 1.5. Further, the estimate assumes that a d_{50} of 10.5 μm and a slope of 1.6 define the PM_{10} sampler's performance characteristics.

The purpose of this manuscript is to explore the potential impacts associated with determining PM_{10} emission values for cotton gin exhausts using the CARB's Method 501 or EPA's Method 201a. Further, the information presented in this manuscript will serve as the basis for conducting additional tests to determine the PSD characteristics and the true PM_{10} percentages of the ten process streams associated with a standard cotton gin.

Procedures

Ideally, the issue put forth in this manuscript would be addressed with data collected from TSP source sampling. The filters obtained from the source sampling would be analyzed with a coulter counter to determine the PSD characteristics associated with each of the 10 process streams. However, to date the sampling tests have not been conducted but are planned for the near future. Therefore, the issue will be approached theoretically from two different standpoints. First, the 1996 AP-42 emission factors for cotton gins along with the information presented in Buser et al. (2001a) and Buser et al. (2001b) will be used to estimate true PM_{10} emission values. The second method will be based on the hypothesis that the PSD's associated each of the 10 process steams will not significantly differ and that the PSD's of the material entering the abatement devices will not significantly differ from the PSD's exiting the devices.

Method 1

The 1996 AP-42 emission factors for cotton gins, shown in Table 1, are a result of data generated through source sampling and the political process. The following broad assumptions were made about the AP-42 data:

1. the emission factors presented in Table 1 represent typical values that can be expected from an average cotton gin;
2. the values were obtained using a sampling method consisting of cyclone, used to separate the larger particles from the smaller particles;
3. the performance characteristics of the cyclone are a d_{50} equal to 10.0 ± 1.0 μm and a slope of 1.5 ± 0.1;
4. the TSP emission factors can be modified to incorporate 10 process streams as described by Buser et al. (2001a);
5. the PSD of the dust exiting the abatement devices can be described by a lognormal distribution; and
6. the performance of the abatement devices can be described by a lognormal distribution.

The PM_{10} percentages associated with the AP-42 data were used with the following equations that were discussed in Buser, et al. (2001b) to determine an estimate of the true percent PM_{10}:

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

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

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

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

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.

In order to determine the PSD MMD of the AP-42 emission factors, equation 3 was solved through a trial and error process using the following assumptions:

1. d_{50} = 11μm;
2. slope = 1.6; and
3. GSD = 2.0.

The assumed sampler performance characteristics correspond to the upper limit of the characteristics documented by EPA. A GSD of 2.0 is reasonably close the GSD's determined for method 2, and will be discussed in the next section. Using these assumptions and setting C_t equal to the respective percent PM_{10} value in Table 1, the MMD's for each emission factor were determined by trial and error. The true percent PM_{10} was determined by solving equation 4 using the MMD's determined by equation 3 and the assumed values for d_{50}, slope, and GSD.

The true percent PM_{10} values were used to determine the pounds of PM_{10} per bale by multiplying the values by the corresponding 1996 AP-42 TSP emission factors. The true PM_{10} values were modified to incorporate 10 process streams using the methods presented in Buser et al. (2001a). Further, the methods and procedures used by Buser et al. (2001a) were used to calculate the emission concentration and rates for the estimated true PM_{10}.

Method 2

The micro-gin at the USDA/ARS Cotton Ginning Research Laboratory in Stoneville, Mississippi was used to collect cotton gin by-product samples from each of the individual machines used when processing picker and stripper harvested cotton. For the picker harvested cotton, samples were collected from the 1st and 2nd incline cleaners, stick machine, lint cleaners, and master trash. For the stripper harvested cotton, samples were collected from the 1st and 2nd incline cleaners, 1st and 2nd stick machines, and lint cleaners.

Three subsamples were randomly collected from each sample and air washed through a 100 micrometer mesh screen. The dust removed from the subsamples was collected on polyweb filters. The particle size distributions of the dust on the filters were determined using the Coulter Counter Multisizer 3. A helium gas density analyzer was used to determine the density of the dusts captured on the filters and these densities were used to adjust the particle size distributions to AED. The Multisizer 3 software was used to determine the MMD, GSD, and true percent PM_{10} for each of the subsamples.

The true percent PM_{10} values were used to determine the pounds of PM_{10} per bale by multiplying the values by the corresponding modified TSP emission factors presented in Buser et al. (2001a). Further, the methods and procedures used by Buser et al. (2001a) were used to calculate the emission concentration and rates for the estimated true PM_{10}.

Results

Method 1

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 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. Further, the pounds of PM_{10} and TSP will be higher for covered condenser drums than cyclones, but the percent PM_{10} will be lower. 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 results of the trial and error calculations using equations 3 and 4 to determine the MMD and true percent PM_{10} are shown in Table 2. The true percent PM_{10} was multiplied times the 1996 AP-42 TSP emission factors and the results are shown in Table 2. Using this scenario to estimate the percent true PM_{10}, reduces the overall PM_{10} percentage from 39.3% to 28.4%. This estimate, suggests that PM_{10} values determined by the CARB Method 501 or EPA's Method 201a are over-estimated by about 38%.

The percent true PM_{10} values were used in the methods and procedures described by Buser et al. (2001a) to determine the PM_{10} emission concentrations and rates associated with a standard 20 bale per hour gin. The results, including the adjusted emission factors are shown in Table 3. The resulting strategies for reducing PM_{10} emissions based on reducing the overall emission concentration or emission factors are shown in Table 3. The strategies are identical to the scenarios presented by Buser et al. (2001a); however, emission factors and concentrations are much lower since the values correspond to true PM_{10} values. For example, the mote fan has the highest emission concentration (132 mg/m^3) and the 1^{st} lint cleaner has the highest emission factor (0.313 lbs true PM_{10}/bale).

Method 2

Particle size characteristics were determined for all the collected subsamples, except the subsamples collected from the lint cleaners. The lint cleaner subsamples were air washed for approximately 30 minutes (about twice the processing time used for the other subsamples), and only a very light filter loading was obtained. This was primarily due the high lint content contained in the samples. The lint cleaner filter loadings were too low to complete reliable Coulter Counter PSD's.

Average densities of the dust less than 100 μm associated with the collected subsamples are shown in Table 4. There were significant differences in the densities of the dusts collected from the picker and stripper harvested cottons and between the individual machines. In general, the dust associated with picker harvested cotton had a higher density than the dust associated with stripper harvested cotton. Further, the dusts associated with the incline cleaner and master trash were higher than the dust associated with the stick machines.

The densities were used to adjust the particle diameters to aerodynamic equivalent diameters, using the following equation and the Multisizer III software:

$$d_{AED} = d_p * \sqrt{\frac{\rho_p}{\rho_w}}$$

where,

d_{AED} = aerodynamic equivalent diameter;
d_p = particle diameter;
ρ_p = particle density; and
ρ_w = density of water (1.0 g/cm^3).

After the AED correction was made, the software was used to determine the $d_{15.9}$, d_{50}, $d_{84.1}$, and percent of particles less than 10 μm for each subsample. Geometric standard deviations were then determined using the following equation:

$$GSD = \sqrt{\frac{d_{84.1}}{d_{15.9}}}$$

The average PSD characteristics are shown in Table 4. There were significant differences detected in the d_{50}, GSD, and percent of particles less than 10 μm obtained from the different machinery. In general, there was a higher percentage of true PM_{10} (smaller d_{50}) in the dust from the stick machine subsamples (both picker and stripper) as compared to the dust from the incline cleaners and master trash subsamples (both picker and stripper). It should be noted that although the percent of true PM_{10} was higher for the stick machines, the concentration of particles was substantially lower for the stick machine subsamples as compared to the incline and master trash subsamples. The GSD's for the mater trash and the 2nd stick machine (stripper cotton) were slightly larger than the GSD's for the other subsamples.

Due to the differences in PSD characteristics and filter loading between the stick machine and other subsamples, the Multisizer III software was used to average all the PSD's and average all the PSD's except the PSD's related to the stick machine subsamples. The characteristics associated with each of the averages are shown in Table 4. Due to the lower concentrations associated with the stick machine subsamples, the impact of including the PSD's did not substantially impact the overall average. Therefore, the average of all the subsamples was used to estimate the true percent PM_{10} associated with a standard cotton gin exhausts. Based on the method two's hypothesis, the MMD, GSD, and true percent PM_{10} were determined to be 18 μm, 2.2, and 24% for each of the 10 process stream exhausts. Using this scenario to estimate the percent true PM_{10}, reduces the overall PM_{10} percentage from 39% to 24%. This estimate, suggests that PM_{10} values determined by the CARB Method 501 or EPA's Method 201a are over-estimated by about 63%.

The percent true PM_{10} values were used in the methods and procedures described by Buser et al. (2001a) to determine the PM_{10} emission concentrations and rates associated with a standard 20 bale per hour gin. The results, including the adjusted emission factors are shown in Table 5. The resulting strategies for reducing PM_{10} emissions based on reducing the overall emission concentration or emission factors are shown in Table 5. The strategies are identical to the scenarios presented by Buser et al. (2001a); however, emission factors and concentrations are much lower since the values correspond to true PM_{10} values. For example, the mote fan has the highest emission concentration (111 mg/m^3) and the 1st lint cleaner has the highest emission factor (0.261 lbs true PM_{10}/bale).

Conclusions

Ideally, the percent of true PM_{10} emitted by individual process streams of a cotton gin would be determined through TSP source sampling, where the filters collected from sampling would be analyzed using the Coulter Counter. However to date, actual sampling has not be completed. Therefore, two theoretical methods of estimating the percent of true PM_{10} emitted for cotton gin exhausts were explored.

Method one utilized the current 1996 AP-42 emission factors and the performance characteristics associated the sampling cyclones used in EPA's Method 201a. The percent of true PM_{10} was estimated to be about 28%. This estimate was 38% less than the percent obtained by dividing the total PM_{10} emission factor by the total TSP emission factor reported in the 1996 AP-42. In terms of emission factors, the estimate obtain through method 1 was 0.865 lb to true PM_{10}/bale as compared to 1.2 lb of PM_{10}/bale reported in the 1996 AP-42.

Method two was based on the hypothesis that the PSD's associated each of the 10 process steams will not significantly differ and that the PSD's of the material entering the abatement devices will not significantly differ from the PSD's exiting the devices. The percent of true PM_{10} was estimated to be about 24% and the corresponding total true PM_{10} emission factor was estimated to by 0.723 lbs/bale. This estimate was 63% less than the percent obtained from the 1996 AP-42.

Based on the results of these two methods, it is anticipated that the true PM_{10} emitted by cotton gin exhausts are considerably lower than the PM_{10} values reported in AP-42. Therefore, when cotton gins are regulated based on PM_{10} emission factors from AP-42 or emission factors derived from source sampling based on CARB's Method 501 or EPA's Method 201a they 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.

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Table 1. Cotton gin emission factors from the 1996 AP-42.

Source	Total PM (lb/bale)	PM_{10} (lb/bale)	PM_{10} (%)
Unloading Fan	0.29	0.12	41.4
1st Seed Cotton Cleaning	0.36	0.12	33.3
2nd Seed Cotton Cleaning	0.24	0.093	38.8
Overflow Fan	0.071	0.026	36.6
Lint Cleaners (screened drums)	1.1	ND	50.0
Lint Cleaners (cyclones)	0.58	0.24	41.4
Mote Fan	0.28	0.13	46.4
Battery Condenser (screened drums)	0.17	ND	50.0
Battery Condenser (cyclones)	0.039	0.014	35.9
Master Trash Fan	0.54	0.074	13.7
Cotton Gin Total	3.05	1.2	39.3

Table 2. Estimated PM_{10} percentages and mass median diameters corresponding to the 1996 AP-42 emission factors.

Source	Mass Median Dia. (μm)	True PM_{10} (%)	Est. True PM_{10} (lb/bale)
Unloading Fan	13.2	34.4	0.100
1st Seed Cotton Cleaning	15.8	25.5	0.092
2nd Seed Cotton Cleaning	14.0	31.4	0.075
Overflow Fan	14.7	28.9	0.021
Lint Cleaners (screened drums)	13.2	34.4	0.378
Mote Fan	11.9	40.1	0.112
Battery Condenser (screened drums)	14.9	28.3	0.048
Master Trash Fan	27.5	7.2	0.039
Total			0.865

Table 3. Emission parameters based on a 20 bale per hour gin using method 1.

Process	%Flow	Flow (cfm)	EF (lbs/bale)	ER (lbs/hr)	EC (mg/m^3)	EC (gr/ft^3)	Strategy Based on Emission Factors	Strategy Based on Emission Concentration
1	11%	14897	0.124	2.47	44	0.0194	2	
2	11%	14897	0.070	1.39	25	0.0109		
3	10%	14153	0.039	0.77	15	0.0064		
4	10%	13408	0.015	0.31	6	0.0027		
5	2%	3119	0.066	1.31	112	0.0491		2
6	10%	13408	0.031	0.62	12	0.0054		
7	2%	3119	0.077	1.54	132	0.0578	3	1
CF Total	55%	77000	0.421	8.42	29	0.0128		
8	15%	21000	0.313	6.26	80	0.0348	1	3
9	15%	21000	0.058	1.16	15	0.0064		
10	15%	21000	0.073	1.47	19	0.0082		
AF Total	45%	63000	0.444	8.88	38	0.0164		
Total	100%	140000	0.865	17.30	33	0.0144		

Table 4. Particle size characteristics of cotton gin by-products obtained from individual gin machinery.

Machine	Density (g/cm^3)	D_{50} (μm)	$D_{15.9}$ (μm)	$D_{84.1}$ (μm)	GSD	PM_{10} (%)
Stripper						
1st Incline Cleaner	1.62	19.4	8.6	37.2	2.1	19.9
2nd Incline Cleaner	1.58	19.2	8.0	35.4	2.1	22.2
1st Stick Machine	1.56	16.2	6.8	31.6	2.2	27.4
2nd Stick Machine	1.54	15.2	5.9	31.3	2.3	31.7
Picker						
1st Incline Cleaner	2.15	17.8	8.3	36.7	2.1	21.8
2nd Incline Cleaner	1.96	18.6	8.2	39.2	2.2	21.5
Stick Machine	1.63	16.9	7.6	33.6	2.1	25.2
Master Trash	1.98	18.2	6.9	37.8	2.3	25.9
Average (with SM)		17.9	7.6	35.8	2.2	23.7
Average (no SM)		18.6	8.0	37.2	2.2	22.2

Table 5. Emission parameters based on a 20 bale per hour gin using method 2.

Process	%Flow	Flow (cfm)	EF (lbs/bale)	ER (lbs/hr)	EC (mg/m^3)	EC (gr/ft^3)	Strategy Based on Emission Factors	Strategy Based on Emission Concentration
1	11%	14897	0.103	2.07	37	0.0162	2	
2	11%	14897	0.058	1.16	21	0.0091		
3	10%	14153	0.032	0.65	12	0.0053		
4	10%	13408	0.013	0.26	5	0.0022		
5	2%	3119	0.055	1.10	94	0.0411		2
6	10%	13408	0.026	0.52	10	0.0045		
7	2%	3119	0.065	1.29	111	0.0483	3	1
CF Total	55%	77000	0.352	7.04	24	0.0107		
8	15%	21000	0.261	5.23	66	0.0291	1	3
9	15%	21000	0.048	0.97	12	0.0054		
10	15%	21000	0.061	1.23	16	0.0068		
AF Total	45%	63000	0.371	7.42	31	0.0137		
Total	100%	140000	0.723	14.46	28	0.0121		