

**COMPREHENSIVE CHARACTERIZATION
OF COTTON GIN PARTICULATE**

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Abstract

A series of particulate emission tests were conducted on commercial cotton gins in New Mexico and California. All measured exhausts used high efficiency cyclones as emission control devices. In another series of tests, seed cotton from producers in Alabama, Arizona, Arkansas, California, Georgia, Mississippi, Missouri, New Mexico, South Carolina, Tennessee, and Texas was ginned at either the Stoneville or Mesilla Park USDA, ARS Cotton Ginning Laboratories. Particulate emissions during ginning were sampled from the exhausts of the unloading separator and the first lint cleaner. For the commercial gin particulate emission test, total suspended particulate (TSP) for all gins averaged between 0.069 and 0.092 g/m³ (0.03 and 0.04 grains per dry standard cubic foot (gr/dscf)) of air emitted at the cyclone. The PM₁₀ fraction of the TSP ranged between 35 and 69% depending on the method of determination and PM_{2.5} was determined to be between 0.4 and 2.5% of TSP (measured by Coulter Counter). Opacity readings did not correlate with measured TSP. The Hand-held Aerosol Monitor (HAM) correlates well with PM₁₀ levels as determined by the Coulter Counter.

For the laboratory gin test, various analyses were performed on the emission particulate sampled and captured to determine the particulate's physical and chemical composition, the presence of any crop protection/agricultural chemicals, and the levels of endotoxin. Proximate analyses showed that the largest constituent of gin emissions is noncellulosic plant material (range of 43 to 66%), followed by cellulose (range of 17 to 40%), with the remainder being inorganic soil particles and water. X-ray fluorescence determined that there were 19 different elements, including arsenic, lead, and mercury. The occurrence of these elements could be attributed primarily to native soil brought in with the harvested seed cotton. Analyses for crop protection products showed that DEF (from defoliation) is the only crop protection product found routinely in gin external emissions. Exposure at the boundary line (100 yd from the gin exhaust) to any of the

substances detected was fractions of ppb, or in the case of DEF, an average of less than 1 ppb (1 ng/m³). The levels of endotoxin were in the range of a few ng of endotoxin per 100 µg of filter dust. The air concentrations 100 yd from the gin exhaust for both plant protection products and endotoxin are well below levels that produce health concerns. Also, none of the substances detected occurred at levels of any concern for meeting either EPA or OSHA regulations.

Introduction

Cotton gins separate seed cotton into cotton lint fibers and cottonseed, and during this process, trash composed mostly of plant parts and soil is removed. All of these products--seed cotton, lint, cottonseed and trash--are transported by air. The air is discharged into the atmosphere after being cleaned by cyclones, inline filters, or screened condenser drums. Thus, cotton gins, which generally operate less than 3 months each year, are stationary emission sources covered by Clean Air Act regulations (Wakelyn, 1991a; Wakelyn, 1994). There are numerous emission points from the control devices (cyclones, screened condensers, etc.). While cyclones, inline filters, and screened condenser drums are very efficient according to published emission factors, there are over 0.9 kg (2 lb) of total suspended particulates (TSP) with about 0.45 kg (1 lb) of the particulate exhausted into the atmosphere per bale of cotton being less than 10 microns in diameter (PM₁₀) (EPA, 1985). (See table 1.) These external emissions are mostly composed of plant parts, fiber, and native soil that were picked up by the mechanical harvester during cotton harvesting.

The U.S. Environmental Protection Agency (EPA) regulates airborne pollutants, including particulate matter (PM) as one of six criteria pollutants as National Ambient Air Quality Standards (NAAQS). The EPA also regulates hazardous air pollutants (HAP) as National Emission Standards for Hazardous Air Pollutants (NESHAP). In 1987, EPA revised the NAAQS for PM, changing it to PM₁₀. EPA has a rulemaking underway to update the PM standard (61 FR 29179, June 12, 1996; 61 FR 65780, Dec. 13, 1996). EPA proposed adding standards for PM_{2.5} to existing annual and 24-hr standards. The EPA Clean Air Science Advisory Council (CASAC) endorsed an addition of a PM_{2.5} standard. There should be a final standard incorporating a PM_{2.5} standard by June 28, 1997. Table 2 shows the current and proposed EPA PM standards.

In November, 1990, Congress amended the Clean Air Act (CAA, P.L. 101-349, Nov. 15, 1990). The amended act set new requirements for federally enforceable operating permits for attainment of PM regulations and expanded the lists of HAPs (air toxics) (CAA, Sec. 112b; 40 CFR 61). The HAPs list was expanded from the seven emission standards, which were set from 1978 to 1990, to 188

substances including arsenic compounds (inorganic including arsine), other soil element compounds (e.g., antimony, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, and selenium), and some pesticides which can be used on cotton (e.g., Captan, Carbaryl [Sevin], Parathion, and Trifluralin [Treflan]) and some which are no longer used on cotton (Wakelyn, 1991b) (See table 3).

Under the CAA, for the most part, states enforce the standards. Even if a source is not a major source, most states have their own standards for construction/operating permits, and there are Federal operating permit requirements ("Title V permits"). In some states, Title V permits and state permits will be combined, and in other states, facilities will be required to have both a state or county (air district) permit and a Title V permit. Also states can require a gin facility to do air dispersion modeling to show that they are meeting the NAAQS for PM at the boundary line (Williams and Parnell, 1995). When a permit is being renewed, it has to be noticed to the public, who can file complaints and request a hearing. If there are health complaints, the state is concerned that people living near the gin may be exposed to harmful substances from the ginning operation. This could include having to show that the exposure to any EPA HAP or OSHA air contaminant (permissible exposure limit, PEL) was below levels of concern (tables 3 and 4 list the EPA HAP and OSHA PELs of concern, respectively). Several states have requested information on the composition of gin external emissions because of the EPA and OSHA concerns raised. Several states have raised concerns that gin external emissions are similar to cotton particulate in a textile mill and could cause respiratory disease and/or that there are agricultural chemicals in the particulate that cause neurobehavioral problems.

Little has been published concerning the chemical composition of the external emissions from cotton gins; research to date has dealt mainly with particulate in the workplace environment of textile mills, cotton warehouses, and cotton gins. Columbus et. al (1984) sampled the exhaust of the lint cleaners of a gin and found minute quantities of arsenic, a normal soil constituent, when the gin was processing cotton that had not been desiccated with arsenic acid. The amount of arsenic in the emissions increased when the gin was processing cotton that had been desiccated with arsenic acid. During the test, the ambient air samples also showed trace amounts of arsenic. Another study by Columbus (1987) examined the amount of three crop protection chemicals (an insecticide, a herbicide, and a defoliant) on the ginned lint. The study found only small amounts of the defoliant on the lint and the amount was proportional to the foreign matter content of the lint.

Cotton gins are minor sources of particulates (TSP, PM10, and PM2.5) and are not significant source categories for any

hazardous air pollutants as defined by EPA (61 FR 28197, June 4, 1996); however, some of the chemicals included in the list of HAPs may be found in small amounts in gin particulate emissions. The chemical composition of gin external particulates has not been well documented. The purpose of this report is to summarize recent work on determining the particle size distribution, elemental composition, agricultural chemical, and endotoxin content of cotton external emissions (Hughes and Wakelyn, 1996; Hughes et al., 1997; Hughes et al., 1996a, 1996b, 1996c).

Experimental

Particle Size Distribution

During the 1994 ginning season, compliance testing was being done using Method 5 type samplers at several gins in California and one in New Mexico (Hughes and Wakelyn, 1996). A Hand-Held Aerosol Monitor (HAM) was obtained from Shofner Enterprises and was used to take data simultaneously with Method 5 sampling. For New Mexico, information was obtained for 5 emission points that had simultaneous Method 5, HAM, and related opacity readings. Correlations could be made between the measurement methods from these data.

Emission tests in California were source tests made on selected exhausts at five gin plants. Simultaneous sampling was done using Method 5 for TSP and Method 501 for PM10. The Method 501 is similar in concept and operation to EPA Method 5 except that it has a precollector designed to separate the particulate collected into fractions greater than and less than PM10. This method is used by the California Air Resources Board (CARB) for source testing of particulate emissions.

During the majority of the California tests, particulate emitted from the cyclone stack was collected onto a glass fiber filter using a Hi-Vol sampler (40 CFR 50, App. B) operating simultaneously with the Method 5 and 501 samplers. Also, during many of the test runs, multiple HAM readings were taken for comparison to the other methods.

Ginning and Recovery of Filter Dust

To determine the elemental composition, and agricultural chemical and endotoxin content of cotton gin external emissions, the processing of cotton and cyclone particulate collection was conducted at both the USDA, ARS, Cotton Ginning Laboratories at Stoneville, MS and Mesilla Park, NM. Seed cotton was obtained from producers in Alabama, Arkansas, Arizona, California, Georgia, Mississippi, Missouri, New Mexico, South Carolina, Tennessee, and Texas and ginned at the two laboratories.

Modified high-volume samplers were used to sample the cyclone exhaust from the unloader fan and the exhaust of

the condenser on the first lint cleaner. Also, the particulate collected by the unloader cyclone was sampled for analysis.

At the Southern Regional Research Center (SRRC), the particulate was recovered from the filters received from the ginning laboratories. A detailed description of the particulate recovery process is given by Hughs et al. (1996b).

Proximate and Elemental Analysis

At SRRC, the proximate analysis of the particulate samples consisted of gravimetric determination of moisture content, followed by a series of solvent extractions to gravimetrically determine water-solubles, ethanol-solubles, noncellulosic organics, cellulose, and inorganic residue, as originally described by Brown et al. (1977) and detailed by Hughs et al. (1996b). All of the portions except the inorganic residue are attributed to plant and fiber parts.

Table 5 shows the general materials extracted by the water, ethanol and ethanalamine solutions. What was left after the extractions were most of the non-water-soluble inorganic substances and cellulose. Cuene was used to dissolve the cellulose, leaving an inorganic residue.

Ash content was determined gravimetrically (Brown et al., 1977) at SRRC using separate particulate samples from those used for the extractions. Differences between ash content and residue can result from loss of soluble salts during water extraction, release of bound elements during ethanalamine and cuene digestion, and a possible small increase in weight from oxides and carbonates formed during ashing, depending on the elements present.

Table 6 shows the elements measured by X-ray fluorescence and their probable source. Elemental analysis of the samples by X-ray fluorescence was accomplished at SRRC according to standard procedures (Hughs et al., 1996b; Domelsmith et al., 1986). The analytical method used to determine arsenic did not distinguish between inorganic arsenic and inorganic arsenic compounds.

Agricultural Chemical (Crop Protection Products) Analysis

Analysis of the samples for crop protection products was performed by Alabama Pesticide Residue Laboratory, Auburn, AL, in 1994, using standard FDA procedures (FDA Pesticide Analytical Manual 3rd Edition 1994, HHS, PHS, FDA; Methods 302 and 303 Methods for non-Fatty Foods).

Endotoxin Determinations

Endotoxin analyses were conducted by Dr. Robert Jacobs, University of Alabama-Birmingham, Birmingham, AL, using procedures that have been commonly used for analysis of environmental samples in the past (Jacobs et al., 1993; Perkins and Olenchock, 1995). More detail is given

on the endotoxin analysis in Hughs et al., 1997. Endotoxin is reported in weight units (nanograms). Since endotoxin is a naturally occurring biological material and a biological analysis is used, level differences can occur in dust endotoxin results within and between laboratories (Perkins, 1992; Chun and Perkins, 1994; NIOSH, 1995). As discussed in Hughs et al., 1997, to compare our results with the NIOSH suggested threshold, the more appropriate values would be those obtained by dividing the results by five. Both unadjusted and adjusted values are given in Table 14.

Results and Discussion

Particle Size Determinations

Table 7 is a summary of the data from the particulate emissions tests conducted by the State of New Mexico (Hughs and Wakelyn, 1996). The TSP concentrations and the opacity readings were determined by the State using the EPA Method 5 and Method 9 protocols, respectively. The average PM_{2.5} and PM₁₀ were determined by the Coulter Counter (Coulter Electronics, 1975) using the particulate collected on the Method 5 filters. The PM_{2.5} and PM₁₀ figures are the average of 3 determinations. The TSP concentrations ranged from 0.02 to 0.05 grains per dry standard cubic foot (gr/dscf) of exhaust air. This range of particulate emission concentration is similar to that reported by others (Parnell and Mihalski, 1992, and Koontz and Flowers, 1992).

The percentage of particles whose aerodynamic diameter is less than or equal to 10 microns (PM₁₀) is currently being used by most regulators as 50% of TSP. Table 7 shows that the PM₁₀ emissions from the New Mexico Gin as determined by the Coulter Counter ranged from 62 to 75% of TSP. PM_{2.5} determined by the same method ranged from about 2.1 to 2.5% of TSP. Opacity was low on all exhausts and ranged from 0 up to 5%. The highest opacity reading was taken from the exhaust of the first hot-air cylinder cleaner.

Table 8 shows the results of the more-extensive gin emission tests that were conducted in California during the 1994 ginning season. All 33 exhausts sampled used high-efficiency cyclones, but the differences in TSP concentrations reflect the differences of input loading to the cyclones at the different process points. The unloading and first drying system exhausts are usually among the highest concentrations because they are the first systems that begin the seed-cotton cleaning process and handle proportionately more material than subsequent cleaners. The battery condenser is the last exhaust in line so that very little particulate is found in its exhaust air.

PM₁₀ for the California tests were determined 1) by Coulter Counter data, and 2) by method 501. Samples were collected simultaneously for both methods. Table 8 shows

that the average PM10 by the Coulter Counter and method 501 was 67.58 and 34.9% respectively. An analysis of variance (SAS, 1987) shows that the measurement averages are significantly different at the 5% level. Using PM10 determinations by the Coulter Counter to predict PM10 from method 501 in a regression gives a coefficient of determination (R^2) of only 0.16 with the slope of the prediction curve being negative. In other words, the PM10 as determined by the Coulter Counter does not compare with that from Method 501. One indicator of PM10 decreases while the other increases. Using the Coulter Counter measurement to predict field measurement of PM10 by Method 501 would give a very conservative result.

The overall average of PM2.5 from Table 8 is 0.68% with a high of 1.51 and a low of 0.42%. This is somewhat lower than the New Mexico data in Table 7 (average PM2.5 = 2.3%). If a PM2.5 standard for particulate emissions is adopted, the relative quantity emitted by cotton gins will be very low.

A regression analysis for the California data was performed using the HAM readings as the dependent variable and PM10 determinations by both the Coulter Counter and Method 501 as the independent variable. The model R^2 for the HAM readings versus the Coulter Counter PM10 is 0.89. The model R^2 for the HAM data versus the Method 501 PM10 is lower at 0.70. The HAM reading more nearly duplicates the PM10 data from the Coulter Counter than similar data from the Method 501.

A regression analysis was also performed using the opacity readings from Koontz and Flowers (1996) and from New Mexico (Hughes and Wakelyn, 1996) as the dependent variable and particulate concentration as the independent variable. There is a significant relationship between opacity and particulate concentration but the model R^2 is 0.51. In general, as the gin particulate emission concentration increases the opacity will also tend to increase. However, the relationship is so variable that a given particulate concentration could result in a wide range of opacity readings. This kind of variability would make opacity unusable as a tool for determining particulate emission concentrations from cotton gin exhausts.

Proximate and Elemental Composition

Table 9 shows the average results of the proximate analysis for the particulate collected from cottons grown across the belt. A more detailed description of the test results from both the Midsouth and the West is presented by Hughes et al. (1996b). Comparing the lint cleaner exhaust between the two regions shows that the west had a higher level of extractables (approximately 66% vs. 43%), a higher level of fine soil particulate (ash content of 20.4% vs. 12.7%), and a lower level of cellulose (16.6% vs. 40.4%) than did the Midsouth. The difference in extractables and fine soil

particulate is probably partially due to a much higher average rainfall in the south washing off and dissolving some of the soluble salts, fine soils and other extractable compounds prior to cotton harvest.

The average cellulose content of lint cleaner exhaust from the Midsouth cotton was 2.5 times that of the lint cleaning exhaust from the Western cottons. This large of a variation was not expected but could come from several sources. The difference could come from significant differences in the amount of extraneous plant material (also composed of cellulose) harvested with the cotton fiber, as well as varietal differences in the natural loss of small fiber fragments during processing. Another possible explanation for part of the large difference in cellulose levels shown in table 9 is the adjustment, filtration efficiency (screen size), and condition of the lint cleaner condenser screen being used. Variations in screen size or holes in a condenser screen can increase the amount of fiber and other cellulosic material lost in the exhaust.

Other than the much higher level of water extractables in the material captured by the cyclone for the western cottons, and to some extent, the residue level after extractions, the material caught by the cyclones when processing cottons from either region was not greatly different. The particulate from the cyclone exhaust when processing western cottons does not have a similar exhaust to compare to from the Midsouth. However, the proportions of its constituents are not greatly different from and generally fall in between the average proportions of the constituents of both the Midsouth and Western cyclone catches.

Summing the moisture content, extractables, cellulose, and residue after extraction for the exhausts and regions shown in table 9 gives an overall estimate of what would be the expected general composition of gin exhaust particulate. Moisture would be expected to make up from 6 to 11% of the gin exhaust. Since the extractables come primarily from organic materials, small pieces of plant parts would constitute from 43 to 66% of the material exhausted into the atmosphere. Cellulose, primarily small cotton fiber fragments, would contribute from 17 to 40% of the exhausted particulate. It would be expected that the seed cotton cleaning section of the ginning system would have cellulose contents somewhere around 17%, and the various lint cleaning exhausts would be somewhat higher depending on the equipment being used. The remainder of the particulate would be insoluble, inorganic soil particles ranging from 7 to 23% of the total as indicated by the residue remaining after extractions. If ash content is considered a better indicator of the actual amount of soil present in a sample, then the range of soil exhausted from a gin as particulate would be from 13 to 34%, and the amount of extractables credited as plant material would be slightly lower.

Similar comments could be made from the averages in table 9 for the material that was caught by the cyclones. Since this material was removed from the air stream and not exhausted as particulate, but is disposed of in some approved manner, this material is not of concern as far as HAPs or PELs are concerned. The information on the contents of the cyclone capture has been included solely as additional information as to the nature of the extraneous material handled by a ginning system.

Table 10 shows the average X-ray fluorescence analysis of samples from across the cotton belt. The average elemental analysis of the particulates from the various exhausts shows that the percentage of the 19 elements varies from about 6.5% to 18% of the total. Except for the possible influence of some residual arsenic remaining in the soil from past application of harvest aid or post emergent herbicide chemicals in the west, the levels of the various elements (including arsenic) are what would be expected from the soil particles present in the sample. Any variation from region to region or between exhausts would very likely be primarily attributable to soil type and composition changes.

In terms of risk assessment to surrounding populations from gin particulate emissions because of HAPs, the averages in table 10 can be used to estimate the severity of any health risks present. Table 1 gave a maximum total suspended particulate (TSP) emission factor for gins of 1.4 kg/bale (3.1 lb/bale). As of the 1995 crop year, the average gin in the United States ginned a total of 14,642 bales of cotton (Mayfield, 1996). Using the TSP of 1.4 kg/bale (3.1 lb/bale), the average U.S. gin emitted a total of 20,499 kg (45,192 lb) of particulate from its exhausts. From table 10, using the worst case for arsenic, mercury, and lead, the average gin would emit a total of no more than 0.19 kg (0.42 lb) arsenic, 0.009 kg (0.02 lb) mercury, and 1.02 kg (2.25 lb) lead. These levels of emission are several orders of magnitude below the threshold level of 9,072 kg (10 tons/yr) to be considered a major source. Most of the metals detected by X-ray fluorescence analysis and summarized in table 10 can be attributed to native soil content, and the minute levels reported can be considered to be insignificant.

Besides the total weight of emission to consider, there are the OSHA PELs (table 4) of airborne concentrations resulting from the particulate emissions that are exhausted from the ginning system. Table 1 shows that, of the maximum total weight of particulate per bale emitted from a ginning system (1.41 kg (3.1 lb)), about 0.54 kg (1.2 lb) is considered PM10. Particulate in the PM10 range will be transported some distance in the atmosphere and contributes to the airborne concentrations of pollutants. Modeling has been done using similar PM10 concentrations to the 0.54 kg/bale (1.2 lb/bale) from table 1. Williams and Parnell (1995) reported on particulate dispersion modeling of a cotton gin using an emission factor of 0.53 kg/bale (1.16

lb/bale), downwind distances from 100 to 1000 m (328 to 3,280 ft) in increments of 100 m (328 ft), and using a standard Gaussian model. The calculated 24-hour time weighted average airborne concentrations of particulate ranged from a low of 70 $\mu\text{g}/\text{m}^3$ to a high of 98 $\mu\text{g}/\text{m}^3$. Using a maximum concentration of 100 $\mu\text{g}/\text{m}^3$ as an index of exposure to the total gin emission particulate, and the average levels of cellulose in table 9 and the elements listed in table 10, the probable exposure to the substances listed in table 4 can be estimated.

Table 11 gives the estimated exposure to the elements and materials found in gin emission particulate whose PELs are listed in table 4. As can be seen in comparing the two tables, most of the PELs in table 4 are in mg/m^3 , and the estimated concentrations in table 11 are in $\mu\text{g}/\text{m}^3$, 1000 times below the PEL of most of the materials. Even the concentration estimate of those elements such as arsenic and cadmium, whose PELs are 10 and 5 $\mu\text{g}/\text{m}^3$, respectively, are still orders of magnitude (at least 1000 times) below the limit in table 4.

Agricultural Chemicals (Crop Protection Products) Composition

The summary of the results of the analysis of cotton gin external emissions for residues of crop protection products is in table 12. Hughs et al. (1996c) give a detailed report on the extent of the findings of the residues on cottons from various states. There were a total of 17 samples analyzed for chemical residues. The results were as follows:

DEF (S,S,S-tributylphosphorotrithioate; defoliant/harvest aid) was found in all 17 samples (0.14 to 44.0 ppm; ave. 8.5 ppm).

Dursban [(Chorpyrifos; 0,0-diethyl 0-(3,5,6 trichloro-2-pyridyl) phosphorothioate)] was found in 4 of 17 samples (0.17 to 0.90 ppm; ave. 0.43 ppm), all from California.

Malathion (0,0-dimethyl phosphorodithioate of diethyl mercaptosuccinate; insecticide) was found in one sample from AZ at 0.24 ppm.

Toxaphene (camphlechlor; chlorinated camphene containing 67 to 69% chlorine; insecticide) was found in one sample from MO at 0.39 ppm.

DDT/DDE was found in 6 of 17 samples (0.04 to 0.70 ppm; ave. 0.18 ppm). All of these samples but one were from the southern U.S. cotton states.

These findings of very low levels of any crop protection product are consistent with findings of Columbus et al. (1984) for ginned lint from MS. DEF is the only substance used on cotton that was commonly detected. It is not regulated as an EPA HAP or OSHA PEL (table 13). The maximum amount found in any of the samples was 44.0

ppm (average 8.5 ppm). Hughs et al. (1996b) made assumptions based on AP-42 (EPA 1996a) (table 1) that the total suspended particulate (TSP) emitted from a normally controlled gin would be 1.4 kg/bale (3.1 lb/bale), and, of this, approximately 40% would be PM-10. Using the 1.4 kg/bale (3.1 lb/bale) as an estimate of the unit of mass emissions, and, assuming that by weight, DEF made up a maximum of 44.0 ppm of the mass, an estimate of the total amount of material released to the environment can be made. Using the same 20,000-bale/yr gin operation used earlier, the 44.0-ppm maximum and 8.5-ppm average mass concentration of DEF translate to a maximum of 1.2 kg/yr (2.7 lb/yr) and an average of 0.24 kg/yr (0.51 lb/yr) released from the gin-particulate emission-control system based on this data. This is an insignificant amount of DEF when, to be a major source for a HAP, there must be an emission of 10 tons/yr or more.

Likewise, the resultant respirable concentration of DEF from the 44.0-ppm maximum and 8.5-ppm average mass concentration from the 20,000-bale/yr gin operating at 28 bales/hour, would be about 3.1 ppb (ng/m^3) DEF with an average exposure of 0.6 ppb.

The degree of risk to the general public associated with these estimated DEF air concentrations was addressed by Hughs et al. (1996c). Based on animal inhalation studies by Pauluhn (1992) and Thyssen and Schilde (1978), the estimated air concentrations of DEF 100 meters from the gin exhaust are well below levels that would produce any health concerns.

DDT, which was found in trace amounts in 6 of 17 samples (0.04 to 0.70 ppm; ave. 0.18 ppm), is not registered for use on cotton and has not been used on cotton since the early 1970's. It is possible that a trace could still be in some soils, which could explain the trace amounts found. Of the substances detected, only DDE/DDT is an EPA HAP (table 13). The maximum amount of 0.70 ppm translates to a maximum of 0.02 kg/yr (0.043 lb/yr) from a 20,000-bale/yr (28-bales/hour) gin, which is an insignificant amount. The maximum level of DDT detected of 0.70 ppm in the particulate emissions would result in an exposure to the public of about 0.05 ppb (ng/m^3) DDT (24-hour time weighted average (TWA)) at 100 m from the gin exhaust. The average exposure from the 6 samples detected would be about 0.01 ppb (ng/m^3). This is well below levels that would produce any health concerns.

Malathion and toxaphene, which are insecticides used before boll opening, are not regulated as EPA HAPs but are regulated with OSHA workplace PELs (table 13). Each of these was found in trace quantity in only one of the samples. The 0.24-ppm Malathion translates to a maximum of about 0.007 kg/yr (0.015 lb/yr) and the 0.39-ppm toxaphene translates to a maximum of about 0.011 kg/yr (0.024 lb/yr) released from the gin (20,000 bale/yr) particulate emission control system. The exposure level at

the boundary line (100 m downwind from the gin exhaust) for these substances, in the one sample where each was found, would be about 0.02-ppb (ng/m^3) Malathion and 0.03-ppb (ng/m^3) toxaphene (24-hour TWA) -- well below the OSHA PEL for Malathion of 15 mg/m^3 total (5 mg/m^3 respirable) and for toxaphene of 0.5 mg/m^3 . This is well below levels that would produce health concerns.

Dursban (Lorsban on cotton, another insecticide), which was found only in some of the CA samples, is not regulated as an EPA HAP or OSHA PEL (table 13). The maximum level of Dursban detected of 0.90 ppm translates to a maximum of 0.024 kg/yr (0.054 lb/yr) released from the gin (20,000 bale/yr; 28 bales/hour) particulate emission control system. The maximum level of Dursban detected of 0.90 ppm translates to a maximum exposure at 100 m downwind from the gin exhaust of about 0.06 ppb (ng/m^3) (24-hour TWA). This is well below levels that would produce health concerns.

Exposure to DEF or any other agricultural chemical can occur via ingestion of drinking water, inhalation of air contaminated with the chemicals (Lewis and Lee, 1976) or particulate containing residues of the chemicals. Various health effects including respiratory, neurobehavioral, and ingestion problems are sometimes associated with crop-protection products. The tolerances determined for dietary exposure on the raw agricultural commodity cottonseed and the processed products oil, meal, and hulls are given in table 13. No pesticides should be present in the refined oil (RBD; refined, bleached and deodorized cottonseed oil), since most commercial deodorizers operate at a temperature of 245°-275°C (475°-525°F) under a negative pressure of 2-10 mm Hg, which would remove agricultural chemicals. The tolerance determined for dietary exposure of a pesticide is set by EPA. This legally allowable maximum amount of pesticide residue, that may remain in a product when the pesticide is used properly and reflects levels that ensure consumer protection, is set at a level that includes wide margins of safety (safety factor) -- normally more than 100 to 1000 times lower than the level that causes "no effect" in test animals -- to allow for the uncertainty inherent in calculating human risk on the basis of animal data and the possibility that some people may be extra sensitive to a pesticide (Furley, 1988). For example, a 68-kg (150-pound) adult would have to eat 3000 heads of lettuce each day for the rest of his or her life to ingest the amount of pesticide found to cause health problems in laboratory mice. Even though there is scientific uncertainty about the meaning of any exposure to agricultural chemicals, the exposure for any of the chemicals found in gin external emissions in this study at about 100 m downwind from the gin exhausts would be about 1000 times, or more, less than the tolerances for dietary exposure (ingestion), which would be greater than a one-million-times margin of safety -- a level which should be below any health concerns.

Endotoxin Composition

The summary of the endotoxin analysis is given in Table 14. Hughs and Wakelyn (1997) give a detailed report on the endotoxin determination from which this summary is drawn. The average endotoxin concentration in nanogram endotoxin per 100 microgram of dust (ng endotoxin/100 μg filter dust) for the cyclone capture dust was 2.52 and for the lint cleaner exhaust was 10.26.

The size of the particulate emission of which the detected endotoxin is a constituent is unknown. However, the worst case will be assumed that it is all in the PM10 or smaller particulate range and would all be in a respirable range at 100 m from the gin emission point. Using the earlier assumptions of a 20,000 bale/yr gin based on the work by Williams and Parnell (1995), the maximum airborne concentration 100 m from the gin can be estimated. From Table 14, the maximum estimated endotoxin airborne concentration 100 m from the gin would be 2.73 ng/m³ adjusted/13.6 ng/m³ unadjusted, with an average exposure of 0.35 ng/m³ adjusted/1.86 ng/m³ unadjusted from the cyclone dust and 1.44 ng/m³ adjusted/7.18 ng/m³ unadjusted from the lint cleaner exhaust.

Hughs and Wakelyn (1997) give a description of the determination of the search of a causal relationship between the presence of airborne endotoxin and respiratory problems. Studies have indicated that cotton related dust levels of 200 $\mu\text{g}/\text{m}^3$ or less, do not cause respiratory symptoms in textile mill workers. More specifically, even though a definitive causal relationship between endotoxin and chronic respiratory effects has not been shown, endotoxin levels have been used as a surrogate for determining acute respiratory hazards of cotton related dusts in textile mills. It has been determined that the threshold of respiratory reaction to endotoxin was 170 ng/m³ for non-smokers and 80 ng/m³ for smokers. Finally, a NIOSH study has suggested an upper limit of about 10 ng/m³ of airborne endotoxin as being the point below which even the most sensitive, pre-exposed reactor in a textile mill will not experience any respiratory effects.

Comparing the maximum endotoxin air concentration of 2.73 ng/m³ (adjusted, 13.6 ng/m³ unadjusted) and the cyclone dust average of 0.35 ng/m³ adjusted/1.86 ng/m³ unadjusted and the lint cleaner exhaust average of 1.44 ng/m³ adjusted/7.18 ng/m³ unadjusted directly to the NIOSH upper limit of 10 ng/m³ for the most sensitive textile worker, it is evident that the estimated concentrations of endotoxin 100 m from the gin are below the level of health concern. It should be noted that while the ability to measure endotoxin is limited and the extrapolation/adjustment is valid, the unadjusted endotoxin values are also below the level of concern. Also, using the estimated boundary line concentration calculated by Williams and Parnell (1995) of 70 to 100 $\mu\text{g}/\text{m}^3$ at 100 m from the gin, shows that the total respirable particulate

concentration is below the 200 $\mu\text{g}/\text{m}^3$ used by OSHA in the cotton dust standard for textile mill workers. Since a cotton gin only operates for 3 to 4 months of the year and not year around as does a textile mill, these results indicate that the levels of endotoxin in gin particulate would be far below any level that would be a health concern, either to gin workers or the general public.

Conclusions

Particle Size Distribution

A series of particulate emissions tests were conducted at cotton gins in New Mexico and California. Particulate emissions were estimated using several different methods, and the conclusions are:

1. Average TSP concentrations from high efficiency cyclone exhausts were normally in the range of 0.069 to 0.092 g/m³ (0.03 to 0.04 gr/dscf).
2. The percentage of TSP that was PM10 varied from 35 to 69% depending on the type of determination used.
3. There is very good agreement between the estimate of the PM10 fraction of the TSP emitted from gins in New Mexico and California using the Coulter Counter, 69.4 and 67.6% respectively.
4. Using the Coulter Counter, the amount of PM2.5 varied between 0.4 and 2.5%, with 2.3% being the average in New Mexico and 0.7% the average in California. These numbers indicate gins are not a significant source of PM2.5 emissions.
5. There is good correlation (model $R^2 = 0.89$) between the experimental readings of the Hand-held Aerosol Monitor (HAM) and PM10 as determined by the Coulter Counter. The HAM may be a useful gin management tool for a quick field determination of the PM10 emissions from a gin without having to do Method 5 testing.
6. Even though opacity generally increases as TSP concentrations increase, opacity is currently not useful as a means of determining levels of TSP being emitted from cotton gins.

Proximate and Elemental Composition

Particulate emissions from laboratory cotton gins processing Midsouth and Western cottons were chemically analyzed. In general, the largest constituent of the particulate mass, both exhausted and caught by a cyclone, was plant material (other than cellulose), followed by cellulose, then native soil, and lastly moisture. There were variations between exhausts, between states within regions and between regions, but the same general trends were observed across the test. For both the Midsouth and

Western cottons, the heavier soil particles tended to be captured by the unloading cyclone early in the ginning process.

Elemental analysis of the particulates across the cotton belt shows that the average total content of the 19 elements under examination ranges from about 6.5 to 18%. Their probable sources are primarily plants and native soils, but some small amount may come from wear of gin processing machinery. One element, arsenic, was not found in particulate from Midsouth cottons but was detected at low levels in some Western cotton particulate. Arsenic can be a natural soil component and can also come from residual amounts left in soil from past applications of harvest aid and post-emergent herbicide chemicals. None of the 19 elements were found at unusual levels over native soil content. Their total emission amount or estimated airborne concentration through an average ginning season is far below the threshold level of being a problem source for meeting either EPA or OSHA regulations.

Agricultural Chemical Composition

DEF (from defoliation) is the only substance found routinely in gin external emissions. Exposure at the boundary line (100 m from the gin exhaust) to any of the substances detected was fractions of ppb or in the case of DEF an average of less than 1 ppb (1 ng/m³), well below levels that would produce any health concerns. Also none of the substances detected occurred at levels of any concern for meeting either EPA or OSHA regulations.

Endotoxin Composition

Endotoxin was found in both particulate caught by a cyclone as well as particulate emitted by a lint cleaner exhaust. However, the levels of endotoxin present are well below limits of concern for even the most sensitive individual as suggested by a NIOSH study for year round workers in textile mills.

Disclaimer

Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the USDA or an endorsement by the Department over other products not mentioned.

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Table 1. AP-42 Emission factors for gins.

Old*	New†
With no controls:	With high-efficiency cyclones on all exhausts:
TSP: 3.18 kg/bale (7.0 lb/bale)	TSP: 1.09 kg/bale (2.4 lb/bale) PM10: 0.37 kg/bale (0.82 lb/bale)
With controls:	With screens on the lint cleaner and battery condenser drums and high-efficiency cyclones on all other exhausts:
TSP: 1.02 kg/bale (2.24 lb/bale)	TSP: 1.41 kg/bale (3.1 lb/bale) PM10: 0.54 kg/bale (1.2 lb/bale)

* U.S. EPA. 1985.

† U.S. EPA. 1996a.

Table 2. Current and proposed PM standards.

Current*	Proposed (EPA Recommended)†
24 hour - PM10 of 150 $\mu\text{g}/\text{m}^3$	PM2.5 - 50 $\mu\text{g}/\text{m}^3$ PM10 - 150 $\mu\text{g}/\text{m}^3$
Annual - PM10 of 50 $\mu\text{g}/\text{m}^3$	PM2.5 - 15 $\mu\text{g}/\text{m}^3$ PM10 - 50 $\mu\text{g}/\text{m}^3$ *

Source: 40 CFR 50.6.

† U.S. EPA 1996b.

Table 3. EPA hazardous air pollutants (HAPs; section 112b CAA)*.

Major source threshold: 10 ton/yr of one HAP; 25 ton/yr total HAPs		
	Pesticides that can be used on cotton	Pesticides no longer used on cotton
<u>Metal compounds:</u>		
Antimony compounds	Captan	DDE (metabolite of DDT)
Arsenic compounds (inorganic, including arsine)	Carbaryl (Sevin)	Heptachlor
Beryllium compounds	Dichlorvos	Lindane
Cadmium compounds	Parathion	Methoxychlor
Cobalt compounds	Methyl Bromide	
Lead compounds	Trifluralin (Treflan)	
Manganese compounds		
Mercury compounds		
Nickel compounds		
Selenium compounds		

* Source: 40 CFR 61.

Table 4. OSHA permissible exposure limits for substances (to assure that no employee is exposed to an airborne concentration above the PEL, calculated as an 8-hour time weighted average)*.

Substance	PEL
Aluminum metal (as Al) particulate	15 mg/m ³ total 5 mg/m ³ respirable
Antimony and cpds (as Sb)	0.5 mg/m ³
Arsenic, inorg. cpds (as As)	10 µg/m ³
Arsenic, org. cpds (as As)	0.5 mg/m ³
Barium, soluble cpds (as Ba)	0.5 mg/m ³
Cadmium and Cd cpds (as Cd)	5 µg/m ³
Calcium silicate particulate	15 mg/m ³ total 5 mg/m ³ respirable
Cobalt particulate (as Co)	0.1 mg/m ³
Chromium (II) cpds	0.5 mg/m ³
Chromium (III) cpds	0.5 mg/m ³
Chromium metal and insol. salt	1.0 mg/m ³
Chlorine	1 ppm (3 mg/m ³) ceiling
Manganese cpds	5 mg/m ³ ceiling
Mercury, aryl and inorg. (as Hg)	1 mg/10 m ³
Mercury (organic) allyl cpds (as Hg)	1 mg/10 m ³
Nickel, sol. and insol. cpds (as Ni)	1 mg/m ³
Silicon particulate	15 mg/m ³ total 5 mg/m ³ respirable
Selenium cpds (as Se)	0.2 mg/m ³
Tin cpds (as Sn)	2 mg/m ³
Cellulose particulate	15 mg/m ³ total 5 mg/m ³ respirable
Particulate not otherwise regulated (PNOR; inorganic and organic)	15 mg/m ³ total 5 mg/m ³ respirable
Nuisance dust (inorganic particulate)	15 mg/m ³ total 5 mg/m ³ respirable
Aldrin	0.25 mg/m ³
Dieldrin	0.25 mg/m ³
Endosulfan	0.1 mg/m ³
Endrin	0.1 mg/m ³
Heptachlor	0.5 mg/m ³
Malathion	15 mg/m ³ total
Parathion	0.1 mg/m ³
Paraquat	0.5 mg/m ³
Phosdrin (mevinphos)	0.1 mg/m ³
Toxaphene (chlorinated camphene)	0.5 mg/m ³
Methyl bromide	20 ppm (80mg/m ³) ceiling

* Source: 29 CFR 1910.1000.

Table 5. Proximate analysis*.

		Boiling ethanolamine extractibles	Residue
Water extractible	Hot 95% ethanol extractibles		
Salts	Waxes	Lignin	Non-water soluble inorganic
substances			
Carbohydrates	Some plant pigments	Protein	Cellulose (Cuene soluble)
Proteins	Lipids	Simple carbohydrates	
Amino acids	Glucosides	Pentosans	
Organic acids		Simple acids	
Some phenolics		Some phenolics	
Some pigments			

* Source: Brown et. al, 1977.

Table 6. Probable source of elements.

Soil	Plant	Machinery
Arsenic	Calcium	Iron
Antimony	Phosphorous	Lead
Beryllium	Potassium	Zinc
Cadmium	Sulfur	
Chlorine	Iron	
Chromium		
Cobalt		
Iron		
Lead		
Manganese		
Mercury		
Nickel		
Selenium		
Silicon		

Table 7. New Mexico gin emissions data.

Exhaust description	TSP, gr/dscf	PM2.5 by Coulter counter, %	PM10 by Coulter counter, %	Opacity %
Unloading	0.0368	2.09	68.92	<1
First hot air cleaner	0.0526	2.45	70.95	5
Second hot air cleaner	0.0314	2.51	61.83	<1
Incline over distributor	0.0191	2.24	70.87	0
Motes	0.0295	2.20	74.54	-
Average	0.0339	2.30	69.42	-

Table 8. California gin emissions data.

Exhaust description	TSP, gr/dscf	PM2.5 by Coulter counter, %	PM10 by Coulter counter, %	PM10 by M501, %
Unloading & first dryer	0.1205	1.51	78.96	39.5
Remaining seed cotton cleaning	0.0428	0.70	72.92	27.5
Lint cleaner trash	0.0090	0.42	54.57	41.1
Battery condenser	0.0022	0.64	59.49	41.6
Motes trash	0.0529	0.57	71.81	38.5
Average	0.0382	0.68	67.58	34.9

Table 9. Average proximate analysis of particulate across the cotton belt.

Analysis	Region/particulate source			
	South/L.C. cyclone exhaust capture	South/L.C. cyclone capture	West/L.C. cyclone exhaust	West/L.C. cyclone capture
Moisture content, %	6.0	6.7	10.6	7.0
Water extractables, %	12.0	9.4	24.7	10.2
Ethanol extractables, %	2.0	1.3	1.9	1.3
Ethanolamine extractables, %	29.2	38.5	39.1	37.1
Cellulose, %	40.4	11.6	16.6	21.4
Residue, %	10.4	32.5	7.0	23.0
Ash, %*	12.7	39.6	20.4	33.9

* Ash content was determined using separate samples and is not cumulative with other analysis.

Table 10. Average X-ray fluorescence analysis of particulate across the cotton belt.

Element	Region/particulate Source				
	South/ L.C. Exhaust	South/ Cyclone Capture	West/ L.C. Exhaust	West/ Cyclone Exhaust	West/ Cyclone Capture
Mg,	%0.33	0.46	0.60	1.06	0.81
Al, %	0.23	1.25	0.45	3.24	1.27
Si, %	2.39	8.53	2.66	7.41	4.69
P, %	0.41	0.42	0.38	0.30	0.31
S, %	0.35	0.35	0.76	0.55	0.83
Cl, %	0.14	0.11	0.53	0.41	0.62
K, %	1.18	1.18	2.40	1.52	1.67
Ca, %	1.33	2.08	3.68	2.58	3.54
Cr, ppm	1.22	9.82	4.95	24.99	4.92
Mn, ppm	205	369	227	349	208
Fe, %	0.16	0.65	0.52	1.11	0.48
Ni, ppm	1.21	1.18	2.48	16.08	1.07
Cu, ppm	26	24	45	31	15
Zn, ppm	148	727	338	965	56
As, ppm	bdl*	bdl	3.75	9.41	0.61
Se, ppm	0.12	0.10	0.13	0.10	0.14
Hg, ppm	0.05	0.03	0.29	0.45	0.20
Pb, ppm	8	208	27	50	17
Cd, ppm	0.10	0.13	0.17	0.14	0.13

* bdl=below detection limit.

Table 11. Estimated exposure to selected substances.

Substance	Estimated concentration* ($\mu\text{g}/\text{m}^3$)
Al	3.2
Si	7.4
Cl	0.5
Ca	3.7
Mn	0.04
Ni	0.002
As	0.0009
Se	0.00001
Hg	0.00004
Cd	0.00002
Cellulose	40.4

* Concentration at the boundary line assumes a 20,000 bale/yr (28 bales/hr) gin; modeling indicates a PM concentration of $70 \mu\text{g}/\text{m}^3$ 24-hr TWA exposure, 100 m from the gin exhaust (Williams and Parnell, 1995).

Table 12. Summary of maximum and average levels of agricultural chemicals detected, concentration 100 m from the gin, and total released to the environment.

Substance	Maximum			Average		
	Conc. boundary* (ng/m^3 or ppb)	Total released† (lb/yr)	Conc. boundary* (ng/m^3 or ppb)	Total released (lb/yr)		
DEF	44	3.1	2.6	8.5	0.6	0.51
Dursban	0.90	0.063	0.054	0.43	0.03	0.03
Malathion	0.24	0.017	0.015			
Toxaphene	0.39	0.027	0.024			
DDT/DDE	0.70	0.049	0.043	0.18	0.013	0.01
Arsenic ‡	1.70	0.1	0.09	0.29	0.021	0.02
—	21.9	1.5	1.3	8.2	0.6	0.50

* Concentration at the boundary line. Assume 20,000-bales/yr (28-bales/hour) gin; modeling indicates a PM-10 concentration of $70 \mu\text{g}/\text{m}^3$ 24-hour TWA exposure, 100 m from the gin exhaust (Williams and Parnell, 1995).

† Total released to the environment. Assumes 20,000-bale/yr (28-bales/hour) gin; AP-42 (EPA, 1996a) indicates 3.1 lb/bale TSP.

‡ Sample: — = particulate captured by cyclone; — = particulate captured from cyclone exhaust.

Table 13. Tolerances on cottonseed and cottonseed products for the crop protection products detected in gin external emissions.

Substances	EPA HAPs†	OSHA PEL‡	Tolerances (ppm)*		
			180	185	186
DEF§	No	No	4 (cs)¶	No	6 (cshulls)
Dursban#	No	No	0.2 (cs)	No	No (0.5 (3 corn sunflower oil) hulls)
Malathion**	No	15 mg/m^3 total 5 mg/m^3 respirable	2 (cs)	No (0.6 saf- flower oil)	No (10 cattle feed)
Toxaphene††	No	0.5 mg/m^3	5 (cs)	No	No
DDT/DDE††	Yes	No	No	No	No
Organic As cpds	Yes	500 $\mu\text{g}/\text{m}^3$			
MSA, DSMA			0.7 (cs)	No	0.9 (c s hulls)
Cacodylic acid			2.8 (cs)	No	No
Inorganic AS cpds§§	Yes	10 $\mu\text{g}/\text{m}^3$	No	No	No

* EPA tolerances (40 CFR):

Part 180 permitted on raw agricultural commodity (RAC);

Part 185 permitted on food for human consumption

Part 186 permitted on animal feed.

† EPA hazardous air pollutants (HAPs).

‡ OSHA permissible exposure limit (PEL), 8-hr TWA.

§ (S,S,S - tributylphosphorotrithioate) (CAS No. 78-48-8).

¶ cs = cottonseed.

Lorsban (chlorpyrifos) [0,0-diethyl 0-(3,5,6 trichloro-2-pyridyl) phosphorothioate].

** 0,0-dimethylphosphorothioate of diethylmercaptosuccinate.

†† Not registered for use or used on cotton for over 10 years.

‡‡ Camphlechlor (chlorinated camphene).

§§ Banned, not registered for use on cotton and not used since early 1970's. Trace (avg. 0.18 ppm--one sample 0.70, 5 samples avg. <0.08 ppm) may still be in soil.

§§§ Not registered for use on cotton since 1993.

Table 14. Endotoxin concentration in gin external emissions and in the airborne dust 100 m from the gin.

Sample	ng endotoxin/ 100 µg filter dust	Conc. boundary line	
	(as measured) [‡]	(ng/m ³) [†] (adjusted) [‡]	(as measured) [‡]
<u>(a) Cyclone dust*</u>			
SC	4.39	0.61	3.07
AL	2.24	0.31	1.57
GA	1.86	0.26	1.30
AR	1.66	0.23	1.16
TN	3.31	0.46	2.36
MO	1.81	0.25	1.27
MS	2.39	0.33	1.01
(Avg.)	(2.52)	(0.35)	(1.86)
<u>(b) Lint cleaner exhaust*</u>			
AR	4.59	0.64	3.21
MS	8.83	1.24	6.18
MO	9.70	1.36	6.79
TN	19.48	2.73	13.64
GA	14.65	2.05	10.26
AL	9.09	1.27	6.36
SC	5.47	0.77	3.83
(Avg.)	(10.26)	(1.44)	(7.18)

* Cyclone dust = particulate captured by the cyclone,

Lint cleaner exhaust = particulate captured from the exhaust on the first lint cleaner.

[†] Concentration at the boundary line. Assume 20,000 bales/gr (28-bales/hr) gin; modeling indicates a PM-10 concentration of 70 µg/m³ 24-h TWA exposure, 100 m from the gin exhaust (Williams and Parnell, 1995).

[‡]As measured by Dr. Jacobs

Adjusted = values ÷ 5 to compare with NIOSH determined values (see Hughs et al., 1997)