CHARACTERIZATION OF COTTON GIN PARTICULATE MATTER EMISSIONS – PROJECT PLAN

Michael D. Buser
USDA-ARS Cotton Production and Processing Research Unit
Lubbock, TX
Derek P. Whitelock
USDA-ARS Southwestern Cotton ginning Research Laboratory
Mesilla Park, NM
J. Clif Boykin
USDA-ARS Cotton Ginning Research Unit
Stoneville, MS

Abstract

In 2006, EPA implemented a more stringent standard for particulate matter with an effective diameter less than 2.5 microns ($PM_{2.5}$). The implementation timeline for this standard will vary by state/district regulatory agency. For example, the San Joaquin Valley Air Pollution Control District has proposed to include cotton gins in their $PM_{2.5}$ State Implementation Plan by the end of 2008, under the assumption that the $PM_{2.5}$ emissions from cotton gins are significant enough to warrant further study and possibly even additional control measures above and beyond the current mandate to install enhanced "1D-3D" cyclones on all emission points. All cotton gins across the cotton belt will eventually be impacted by this standard. The primary issues surrounding particulate matter regulations for cotton ginning industry are: 1) limited or lack of $PM_{2.5}$ data; 2) potential over-prediction of current dispersion models; and 3) effects of sampler errors. The cotton ginners' associations across the cotton belt, including the National, Texas, Southern, Southeastern, and California associations, have agreed that there is an urgent need to collect gin emission data to address these issues. In response to the gin association's requests, the project outlined in this paper was developed.

Introduction

In 2006, the United State Environmental Protection Agency (EPA) implemented a more stringent standard for $PM_{2.5}$, particulate matter with an effective diameter less than 2.5 microns (CFR, 2006). $PM_{2.5}$ is listed as a criteria pollutant in the National Ambient Air Quality Standards (NAAQS). All cotton gins will be impacted by this standard. The timeline, in which this standard will be implemented in the individual cotton belt states, will vary by state/district agency. Although California appears to be the first state to address these new federal standards, other states such as Texas will be implementing $PM_{2.5}$ regulations in the near future.

In California, the San Joaquin Valley Air Pollution Control District has proposed to include cotton gins in their $PM_{2.5}$ State Implementation Plan (SIP), under the assumption that the $PM_{2.5}$ emissions from cotton gins are significant enough to warrant further study and possibly even additional control measures above and beyond the current mandate to install enhanced "1D-3D" cyclones on all emission points. In the district's candidate control measures section of the 2008 $PM_{2.5}$ SIP, the district is considering additional control measures such as baghouses, series cyclones, and other technologies which can have substantially higher fixed and variable costs compared to current control measures. If additional control measures, such as baghouses are mandated, the costs will be significant and will likely impact ginning costs.

The primary issue affecting the cotton industry across country in regards to the implementation of the $PM_{2.5}$ standard is the fact that very little scientifically sound information is available on cotton gin $PM_{2.5}$ emissions. Some recent research indicates that current $PM_{2.5}$ sampling methods (developed for sources that emit PM with a relatively small particle diameter) could be over-estimating cotton gin (PM with relatively larger particle diameters) $PM_{2.5}$ emission concentrations by 14 times (Buser et al., 2006a, Buser et al., 2006b, Buser et al., 2006c). This possibly explains why some reports indicate that over 30% of total cotton gin PM emissions are $PM_{2.5}$ and others indicate that this ratio is less than 3%.

States such as Missouri, North Carolina, South Carolina, and New Mexico, are or have used dispersion modeling to estimate cotton gin boundary line PM_{10}, particles less than 10 microns in diameter, concentration levels for comparison with the NAAQS. Cotton gins in states like Missouri, are finding it difficult to meet the requirements necessary to obtain air quality permits through modeling. The EPA recommended dispersion models used by the states were not developed for low-level point sources such as cotton gins. Several studies included in the literature suggest that these models could be over-predicting cotton gin boundary line concentrations by as much as a factor of 10 (Zwicke, 1998; Fritz, 2002). These modeling errors coupled with the $PM_{2.5}$ stack sampling errors could make it extremely difficult for cotton gins to meet $PM_{2.5}$ modeled concentration limits set by the individual states.

In response to this issue, the cotton ginners' associations across the cotton belt, including the National, Texas, Southern, Southeastern, and California associations, have agreed that there is an urgent need to begin collecting gin emissions data that may be used to refute inaccurate data used by state regulatory agencies. At the request of the ginning associations, the USDA-ARS Ginning Laboratories developed a proposal for a four year study to evaluate cotton gin PM emissions at several gins at locations across the cotton belt. The four objectives of the study are as follows:

1) Develop $PM_{2.5}$ emission factors and verify current PM_{10} emission factors for cotton gins through stack sampling.
2) Develop a robust data set that can be used in the design, development, and evaluation of current and future air quality low-level dispersion models. This data set will consist of stack and ambient sampling data.
3) Characterize the PM emitted from cotton gins in terms of particle size distributions, particle density, and particle shape.
4) Collect field data to further quantify federal reference method ambient and stack PM_{10} and $PM_{2.5}$ over-sampling rates.

Project Plan

To achieve the objectives of this work, four to seven sampling sites (based on total contributed funds) will be evaluated. Current plans include sampling a New Mexico gin in the fall of 2008, one South Texas gin in the summer of 2009, two California gins in fall of 2009, a West Texas and a Missouri gin in 2010, and a North Carolina gin in 2011. All gins included in the plan are saw-type gins with the exception of one roller gin in California. The identified gins and initial sampling timeline could change due to unforeseen weather or crop issues. The specific gins sampled will be selected based on the input from a cotton gin advisory group. These gins will be equipped with similar abatement technologies and process streams similar to: module feeder or suction, No. 1 pre-cleaning, No. 2 pre-cleaning, overflow, No. 1 lint cleaning, No. 2 lint cleaning, mote fan, mote trash fan, battery condenser, and master trash. If the selected gins are equipped with additional process streams (e.g. feeder, No. 3 pre-cleaning, No. 3 lint cleaning) these streams will be sampled in the same manner as the ten pre-defined process streams. A generalized cotton gin process stream flow diagram is shown in Figure 1. Thus, results from this study will include replicated data for the pre-defined process streams from the majority of the gins and more limited data on the additional process streams.

Stack Sampling

Prior to testing a specific cyclone, a stack extension, with straightening vanes, will be attached to the cyclone exit tube. A picture of the straightening vanes inside a stack extension is shown in Figure 2 and Figure 3 is a picture of an extension mounted on a cyclone exhaust. Stack sampling will adhere to EPA protocols and will be performed by a certified stack sampling company under the supervision of the investigators. Note: it is anticipated that the same certified stack sampling company will be used at all sites. Stack sampling methods will include:

1) OTM 27 – the EPA method for measuring $PM_{2.5}$ filterable stack emissions
2) Method 201a – a standard EPA method for measuring PM_{10} filterable stack emissions
3) Method 17 – a standard EPA method for measuring total filterable stack emissions

A picture of the sampling heads used in these three methods is shown in Figure 4.

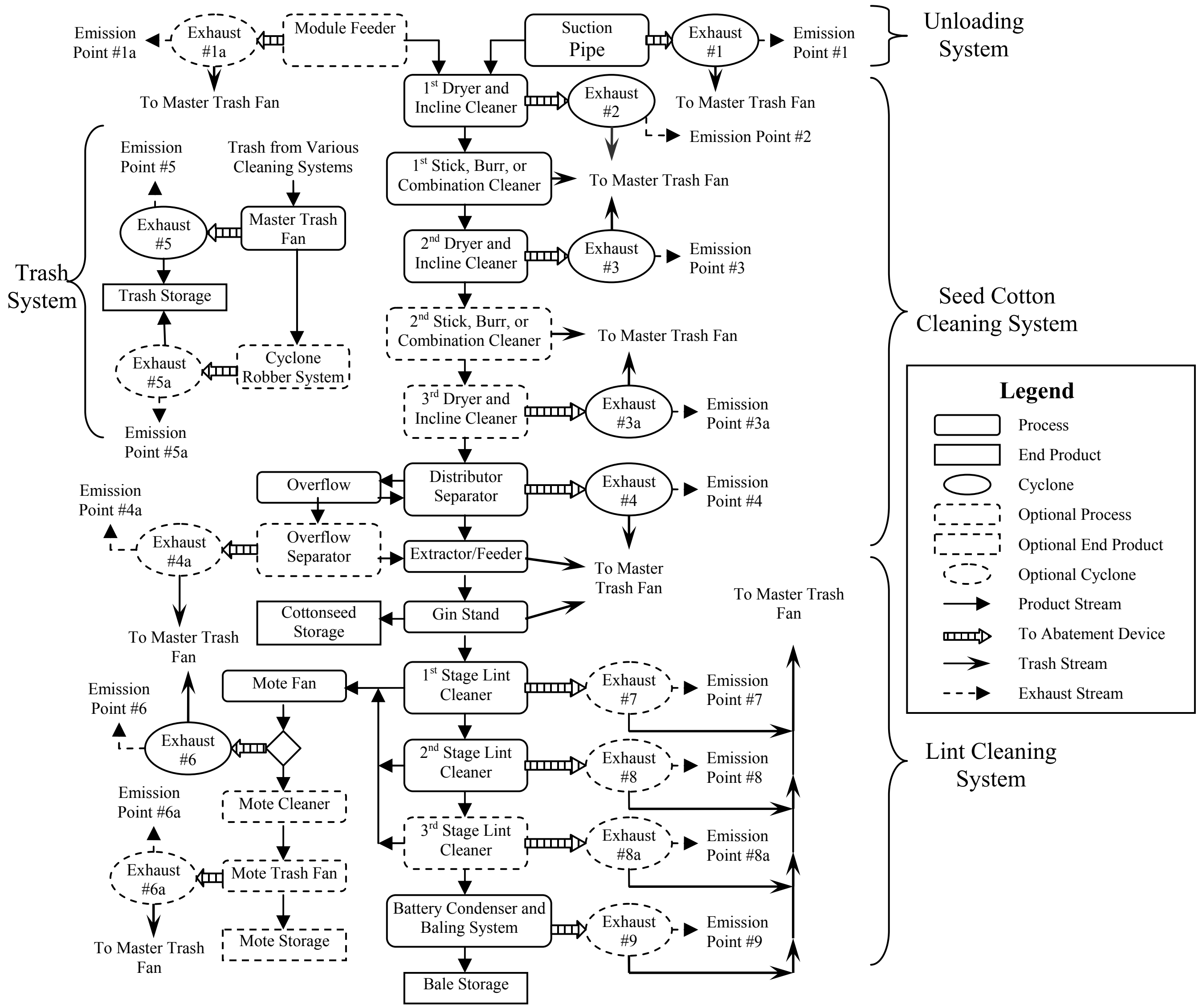

Figure 1. Generalized cotton gin process stream flow diagram (Buser, 2004).

Figure 2. Stack extension with straightening vanes.

Figure 3. Stack extension installed on cyclone exhausts.

Figure 4. OTM 27 (top), Method 201a (middle), and Method 17 (bottom) sampler heads.

Three replications of each sampling protocol will be preformed for each process stream. Forty-seven millimeter Zefluor filters will be used for the primary filters of all sampling methods. All filters and wash containers will be pre-labeled, pre-weighed, and stored in sealed containers at the USDA-ARS Air Quality Laboratory in Lubbock, TX, for shipping to the sampling site. After each test the filters and washes will be retrieved, in accordance to EPA's respective protocol. Chain of custody for all filters and washes will reside with the USDA-ARS. The exposed filters will be stored in individual sealed Petri dishes and packed for transportation to the Lubbock Laboratory. Sampler head acetone washes will be conducted on-site in the USDA-ARS air quality mobile unit that is equipped with a wash hood and a conduction oven housed in separate ventilation hoods. Acetone washes will be dried at 49 ^{o}C and then the wash container will be covered with a lid and placed in individual sealed plastic bags for transportation back to the Lubbock Laboratory. All filters and washes will be analyzed by the USDA-ARS Air Quality Laboratory in Lubbock, TX. This laboratory will work closely with the certified stack testing company in preparing individual source test reports for each site, using EPA's Electronic Reporting Tool.

Ambient Sampling

The ambient sampling portion of this study will begin prior to, during, and continue after the stack sampling portion of the study is completed with a target duration of 15 days. A set of ambient samples will be collected from the ambient sampler network once in every 24-hour period. The actual sampling time will be dependant on the time required to change out filters and prepare for the next run and will be less than 24 hours. Ambient air sampling will be conducted by USDA-ARS personnel and will follow USDA-ARS Air Quality Laboratory protocol. The ambient equipment used in the study will include:

- 12 – ten meter towers for PM sampling.
  - TSP sampler heads located at 1.0, 2.0, 3.0, 4.5, 7.25, and 10 meters.
    - TSP sampler heads are USDA-ARS designed low-volume samplers with a target flow rate of 16.7 lpm.
  - MetOne (Grants Pass, OR) 034B anemometers (wind speed & direction) located at 1.0, 2.0, 3.0, 4.5, 7.25, and 10 meters.
  - Ambient temperature, relative humidity, and barometric pressure collected at approximately one meter.
  - Flow control and data collection system electronics are a USDA-ARS design.
  - Eight readings of wind speed, ambient temperature, relative humidity, barometric pressure, and sampler flow rate collected per second and averaged. Wind direction is collected at one-second intervals.
  - Data is stored on-board in one-second intervals and relayed to the base station in five-minute intervals with an RF modem.
- 48 – stand alone PM samplers.
  - Sampler heads are located at two meters above the ground.
    - Equipped with USDA TSP sampler head, Thermo Scientific (East Greenbush, NY) PM_{10}, BGI Incorporated (Waltham, MA) Well Impactor Ninety-Six (WINS) $PM_{2.5}$, or Thermo Scientific very sharp cut cyclone (VSCC) $PM_{2.5}$ inlets.
  - Optional MetOne 034B anemometer located at one meter
  - Ambient temperature, relative humidity, and barometric pressure collected at approximately one meter.
  - Flow system and data collection electronics are a USDA-ARS design
  - Eight readings of wind speed, ambient temperature, relative humidity, barometric pressure, and sampler flow rate collected per second and averaged. Wind direction is collected at one-second intervals.
  - Data is stored on-board in one-second intervals and relayed to the base station in five-minute intervals with an RF modem.
  - Low-volume samplers with a target flow rate of 16.7 lpm.
- Low-volume ambient sampler heads.
  - 124 - USDA-ARS TSP sampler heads.
  - 12 - Thermo-Fisher PM_{10} (1^{st} stage) inlets.
  - 12 - Thermo-Fisher PM_{10} (1^{st} stage) inlets followed by WINS impactors.
  - 12 - Thermo-Fisher PM_{10} (1^{st} stage) inlets followed by the $PM_{2.5}$ VSCC.
- 4 Thermo Scientific tapered element oscillating microbalance (TEOM) PM samplers.
  - Equipped with Thermo Scientific TSP heads and Thermo Scientific automatic cartridge collection units (ACCU).

A robust uniform sampling array was developed based on the available sampling equipment, to maximize data quality while minimizing the effects of changing wind direction. The sampling array consists of samplers located at thirty degree intervals encompassing the gin, at three radial distances from a pre-determined center point on the gin. As each gin site will be different, this sampling array allows for flexibility in sampler location to account for site restrictions. Also, the magnitude and density of the sampling array will limit the impact of needing to delete some sampling points altogether due to on-site restrictions, such as buildings or roads. An example of an array with deviations is shown in Figure 5. The inner and outer circles are comprised of stand alone samplers and the middle circle is comprised of tower samplers. In this example, three samplers were not deployed in the inner circle because of site restrictions (e.g. buildings) and several of the samplers on the inner and middle circles were moved to accommodate site restrictions (e.g. roadways).

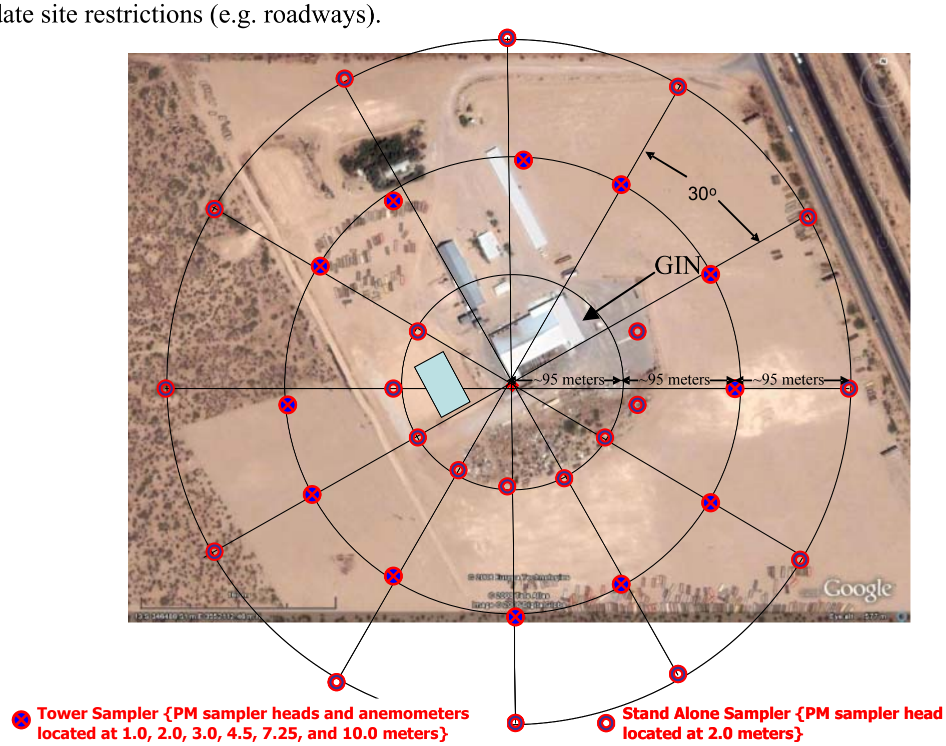

Figure 5. Layout of ambient sampler sites.

Generally, generators would be located at each of the sampling sites to provide electrical power for the samplers. However, due to number of sampling sites and need to conduct stack sampling and ambient sampling simultaneously, the number of generators must be minimized. Each stand alone ambient sampler draws roughly 0.9 amps, requiring only light gauge electrical wire to run approximately 95 meters from a power source to a stand alone sampler. Based on the pre-test site evaluation visits, on-site electrical service sites will be identified and used to the full extent to reduce the number of gasoline powered generators. An example of routing the power is shown in Figure 6. In Figure 6, the dotted lines and stars correspond to electrical lines and power sources, respectively. All electrical lines running though the gin yard, in which the integrity could be compromised by traffic or other normal activities, will be buried approximately fifteen centimeters deep. The research team will work closely with the gin management to identify the most efficient means of powering the samplers, while minimizing the impact on normal gin operations.

The number and order of ambient samplers located at each site may vary. As previously mentioned, stand alone samplers will be deployed at each site on the inner and outer rings (Figure 7). For the middle tower ring there will be six different sampler configurations. Configuration one (Figure 8) will be equipped with one TEOM sampler with a U.S. TSP inlet and ACCU system, one USDA-ARS TSP tower sampling system, two Thermo Scientific ambient PM_{10} sampler heads attached to a USDA-ARS stand alone flow control and data logging system, and two Thermo Scientific ambient PM_{10} sampler heads followed by a Thermo Scientific $PM_{2.5}$ VSCC attached to a USDA-ARS stand alone flow control and data logging system. Configuration two will be identical to configuration one, except the $PM_{2.5}$ ambient samplers will be Thermo Scientific ambient PM_{10} sampler heads followed by a BGI Incorporated WINS impactor attached to a USDA-ARS stand alone flow control and data logging system. The set up will be similar to that shown in Figure 8. Configuration three (Figure 9) will be identical to configuration one with the exception of only one PM_{10} and one $PM_{2.5}$ VSCC being deployed. Configuration four will be identical to configuration two with the exception of only one PM10 and one PM2.5 WINS impactor being deployed; similar to the setup shown in Figure 9. Configuration five (Figure 10) will be equipped with one USDA-ARS TSP tower sampling system, one Thermo Scientific ambient PM_{10} sampler head attached to a USDA-ARS stand alone flow control and data logging system, and one Thermo Scientific ambient PM_{10} sampler heads followed by a Thermo Scientific $PM_{2.5}$ VSCC attached to a USDA-ARS stand alone flow control and data logging system. Configuration six will be identical to configuration five, except the PM2.5 VSCC is replaced with a WINS impactor. For a cotton ginning facility the ambient sampler site arrangements will include: one site each for configurations one, two, three, and four; five sites each for configurations five and six; and up to 24 stand alone TSP samplers.

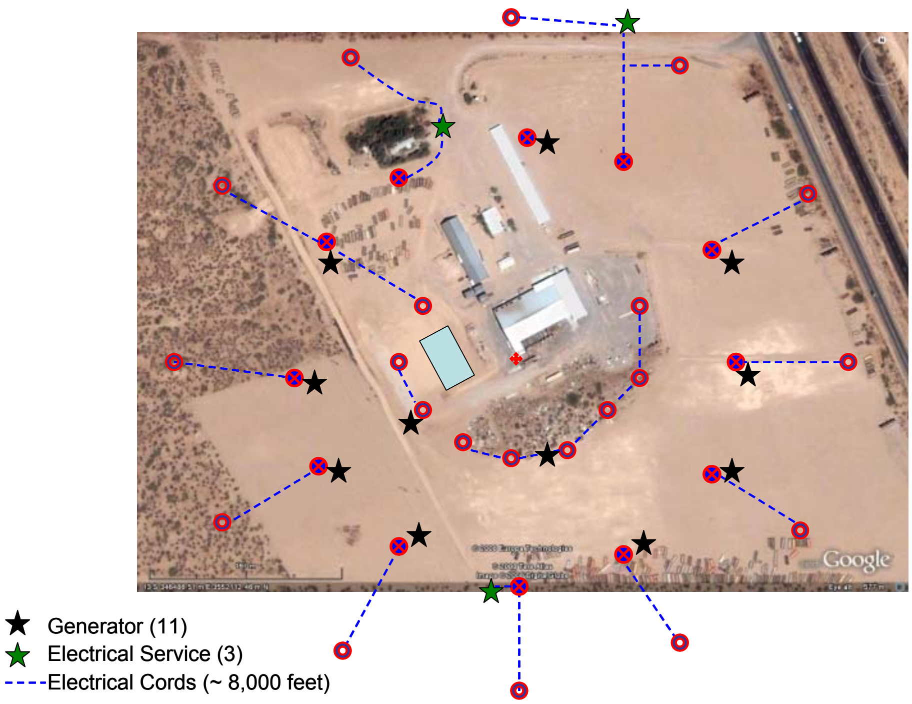

Figure 6. Sampler power distribution example.

Figure 7. USDA-ARS TSP stand alone samplers.

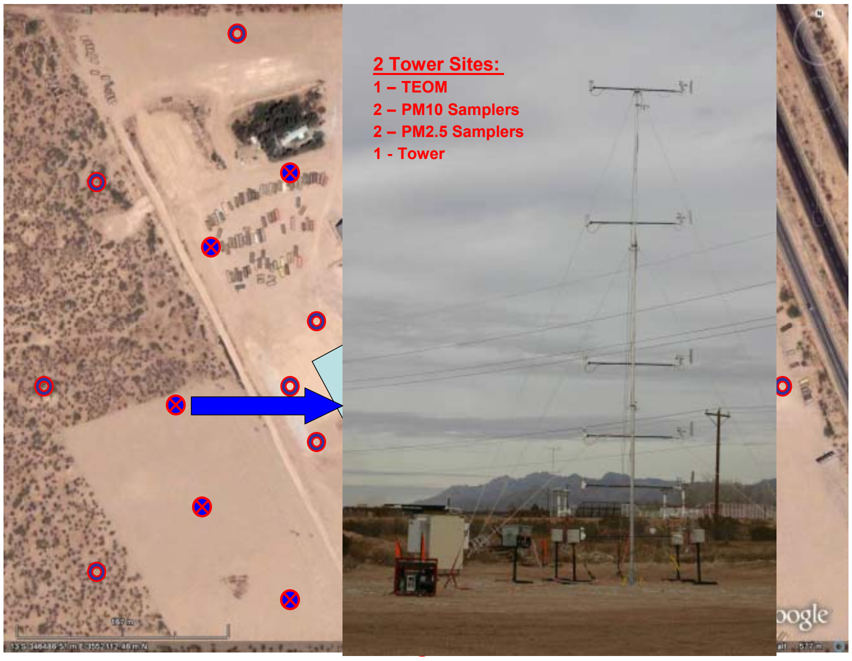

Figure 8. Ambient air sampler site configuration one.

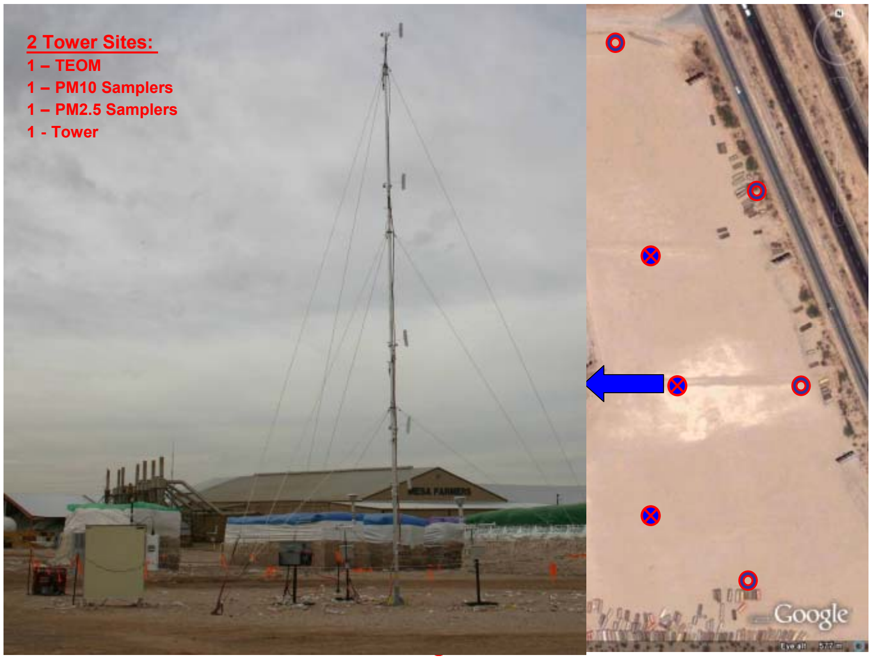

Figure 9. Ambient air sampler site configuration three.

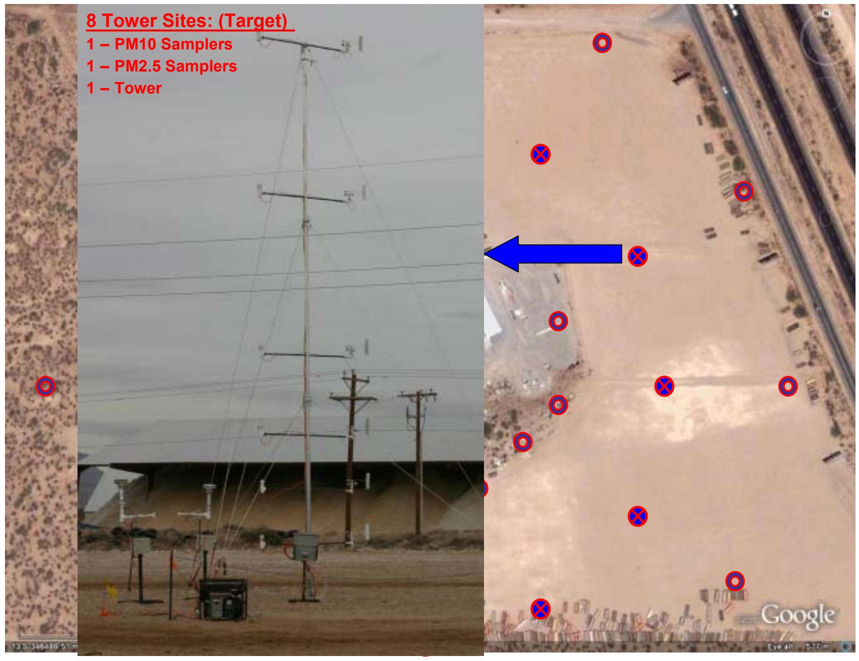

Figure 10. Ambient air sampler site configuration five.

After setup and prior to each sampling run pre-labeled and pre-weighed 47-mm Zefluor filters will be removed from sealed Petri dishes and loaded into filter cassettes in an enclosed room in the air quality mobile unit. The filter cassettes, like the one shown in Figure 11, are stored in air tight canisters for transportation to and from the field and are used to facilitate filter changes; reducing time, errors, and possible contamination. Each deployed sampler head will have two filter cassettes. One cassette with a clean filter will be deployed with a sampler head while the cassette residing in the sampler head with the exposed filter will be retrieved and returned to the mobile unit for extraction. The generalized protocol for retrieval of exposed filters and loading of clean filters dictates that the tower sampler pumps are switched off at 6:00 a.m. and man-lifts used to change out the filters from tower levels three through six. Once these filters are changed, the man-lifts are available for stack sampling and the remaining filters will be switched out from ground level. As remaining filters are changed, the pumps on the stand alone samplers will be shut down, filters will be changed, all pumps including the tower pumps will be started, and the technician will move on to the next ambient sampler site.

As mentioned previously, ambient filters will only be changed once in a 24-hour period. Once the filter cassettes are returned to the mobile unit they will be removed from the sealed container. Then the filters will be removed from the cassette and placed in a Petri dish which is sealed and prepared for transport back to the USDA-ARS Air Quality Laboratory in Lubbock, TX for laboratory analysis. After testing at the site is completed, the secure digital (SD) data storage cards containing flow data will be retrieved from each sampler and shipped to the Lubbock Laboratory for data evaluation and integration.

Laboratory Analysis

Pre- and post-processing of all filter and wash samples from the stack and ambient sampling will be completed at the USDA-ARS Air Quality Laboratory in Lubbock, TX, and will follow the laboratories standard operating procedures (SOP). Depending on the sample, this could include observational, gravimetric, particle size, and/or particle shape analysis. Each sample will be visually inspected for unusual characteristics, such as high cotton lint content or extraneous material. If anomalies are present, digital pictures of the samples will be taken for documentation purposes prior to further analysis.

Gravimetric analysis will be conducted on all samples. Prior to pre- and post-weighing all samples will be conditioned in an environmental chamber (21 $^{+}/_{-}$ 2^{o}C; 35 $^{+}/_{-}$ 5% RH) for 48 hours. The samples will be weighed in the environmental chamber on a Mettler MX-5 microbalance after being passed through an anti-static device. Weights will be digitally transferred from the microbalance to a Microsoft Excel spreadsheet using Mettler's BalanceLink software to reduce errors. Technicians will wear latex gloves and particulate respirator mask covering the mouth and nose when handling samples to avoid contamination. Samples will be weighed three times in batches of twenty. If the standard deviation of the weights for a given sample exceeds 10 µg, the sample will be reweighed as part of the next batch of twenty. Once the pre- and post-gravimetric analyses are completed, the data will be merged and the total mass collected on each filter will be calculated.

Figure 11. Filter cassette with clean filter being deployed in an ambient air sampler.

Particle size analysis will not be completed on all samples. USDA-ARS SOP requires lightly loaded samples not analyzed due to accuracy concerns. A sample's eligibility for particle size analysis is determined by visual inspection and review of the gravimetric analysis results. It is expected that all filters and the majority of the acetone washes from stack sampling will be analyzed. It is expected that approximately 75% of the filters from the ambient sampling will be analyzed. This percentage will greatly decrease for samples collected on days were high wind and/or rain events occurred. Note: particle size analysis is a destructive process so every effort will be made to preserve as much sample as possible for additional analysis, such as particle shape analysis.

The particle size analysis will be conduction on a Beckman Coulter Counter Multisizer III and/or a Beckman LS 230 laser diffraction system. It is expected that roughly 45% of the samples will be analyzed on the Multisizer III, 45% on the LS 230, and 10% will be analyzed on both. Both systems have unique advantages and disadvantages, so both systems will be used in the overall analysis to strengthen the overall data set. Sample preparation for all samples will be identical and will follow the USDA-ARS Air Quality Laboratory's SOP (Buser, 2004). An example of information from the particle size analysis is shown in Figure 12.

Particle shape analysis will be conducted after the size analysis is completed, but will not be conducted on all samples. Because the particle size analysis is a destructive process, the number of samples available for shape analysis will be much lower than that for size analysis. Due to the time involved with the analysis, the number of samples will be reduced even further. It is expected that particle shape analysis will be conducted on 5% of the total collected samples. Samples from the stack testing with high particulate loading, not requiring the whole sample for particle size analysis, will be analyzed for particle shape. The number of available ambient samples for particle shape analysis will be reduced based on the location in which the sample was collected. For example only one sample per tower site will be analyzed. In addition to a digital image of individual particles (Figure 13) the particle shape analyses will return measures of equivalent circular area diameter, least bounding circle diameter, Feret width, Feret length, least bounding rectangle width, least bounding rectangle length, least bounding rectangle aspect ratio, fiber width, fiber length, fiber aspect ratio, sphericity, and perimeter.

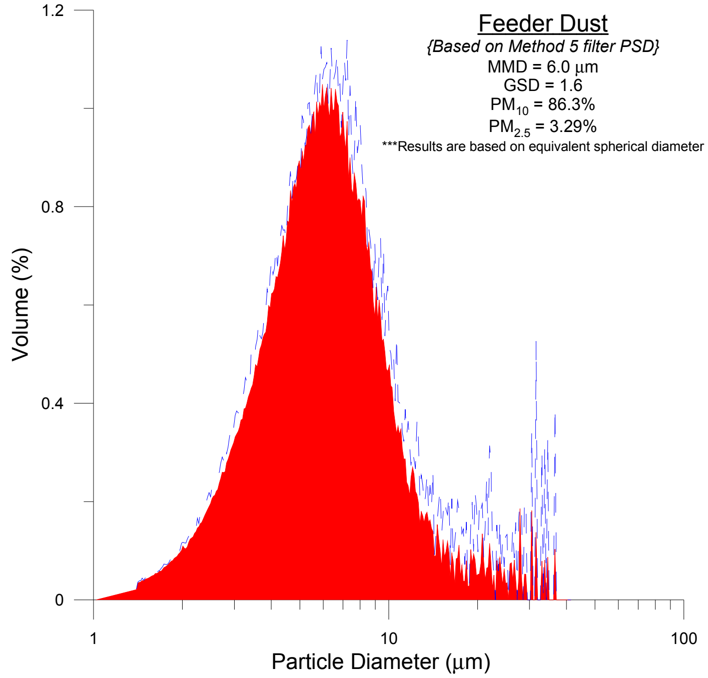

Figure 12. Example of how the particle size results will be reported (red repsents the average distribution and the blue relates to the distribution standard deviation).

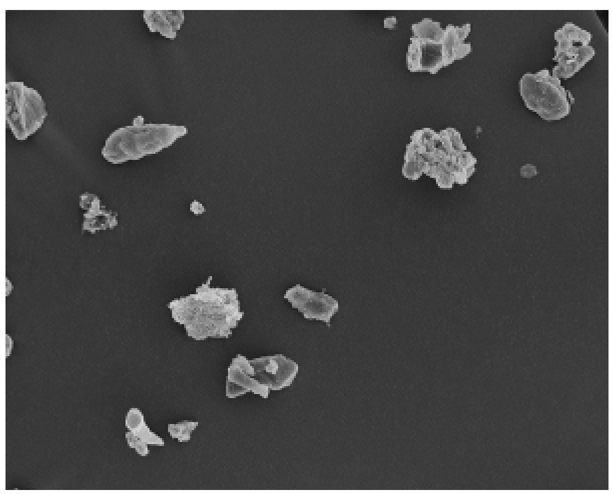

Figure 13. Example of the particle shape analysis digital picture.

When the sample analyses are completed, the data will be merged and combined with the corresponding field data. Emission concentrations and rates will be calculated for the ambient and stack data, respectively. Wind roses, snapshot wind site profiles, temperature and relative humidity profiles, and ambient concentration contour maps will be developed. This information will be captured in individual sampling campaign reports that will be submitted to collaborators for review. After the completion of all sampling campaigns, the entire set of data will be compiled and prepared for publication.

Summary

The development of $PM_{2.5}$ emission factors for gins across the belt will benefit local cotton gins and state air pollution regulatory agencies, by providing sound science based data needed to amend cotton gin air quality permits for $PM_{2.5}$ emissions. Since more and more states are moving towards using dispersion modeling to determine a gin eligibility for an operating permit, the development of a high quality data set that can be used to evaluate and modify current dispersion models is a critical and urgently needed. This data set could be used to develop new more accurate models for low-level agricultural point sources, which would greatly benefit cotton gins and other agricultural processing facilities. Under current regulatory agency assumptions, cotton gins will be regulated and permitted based on $PM_{2.5}$ data that are likely more than 10 to 14 times higher than true $PM_{2.5}$ levels because of over-sampling issues. Conducting this comprehensive study and including state and federal regulatory agencies in all phases of the study, could lead to the over-sampling and model over-prediction problems being addressed in policy and regulatory changes by state and federal agencies.

The goal of this research project is based on environmental stewardship and economic viability. From an environmental perspective: determination of scientifically sound $PM_{2.5}$ cotton gin emissions data. Will cotton gins meet the upcoming $PM_{2.5}$ regulations? Will cotton gins have problems obtaining $PM_{2.5}$ operating permits? From an economic viability perspective: if state regulatory agencies mandate additional cotton gin $PM_{2.5}$ controls, the decisions need to be based on sound science. If substantial abatement system changes are mandated, fixed and variable costs could substantially increase and would likely be passed on to the producers. With cotton production input costs soaring, all input decisions including ginning issues need to be based on sound science. Sound science is a key to ensuring that the US cotton industry remains strong and competitive on the world market.

Acknowledgements

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Disclaimer

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