Proposal #4

Title: Improving the Accuracy of PM_{10} Measurements from Agricultural Sources

Principle Investigator: William Brock Faulkner, Assistant Professor, BAEN

Amount Requested per Year: $ 99,991 FY 2014 $88,924 FY 2015

Executive Summary

Researchers involved in sampling of coarse aerosols such as those emitted from agricultural sources have reported "oversampling" of PM_{10} and $PM_{2.5}$ concentrations when using Federal Reference Method (FRM) PM_{10} inlets (e.g., Buser et al., 2008). Such oversampling bias would lead to more stringent regulations of emissions from agricultural sources of particulate matter (PM). Aerosols emitted from agricultural operations are often characterized by larger particle sizes than typical urban aerosols. Under previous State Air Quality Initiative (SAQI) funding, the PI demonstrated that non-trivial fractions (~3%) of large particles (20-25µm) penetrate the pre-collector of FRM PM_{10} samplers, leading to substantial bias relative to EPA's "ideal" PM_{10} sampler when sampling agricultural PM.

To overcome these sampler bias issues, methods have been developed to calculate "true" PM_{10} and $PM_{2.5}$ emissions using PM samples collected with low volume total suspended particulate (LVTSP) samplers combined with particle size characterization of the collected samples. This method has been employed in numerous studies characterizing emissions from agricultural operations (e.g., feedyards, cotton gins, tillage operations, and harvesting operations). However, under previous SAQI funding, the PI demonstrated that the performance of the LVTSP samplers that have been employed in many of these studies is highly dependent on ambient wind speed, which likely biases both measured concentrations of TSP (negative bias) as well as the measured fraction of TSP that is PM_{10} (positive bias).

Despite observations of "oversampling", there is not universal agreement whether the results constitute an "oversampling bias" for industries in which generated particulates typically exhibit a significant coarse fraction. Scientists at EPA have argued that ambient particle compositions cannot be reconstructed using the techniques employed by Buser et al. (2008) and others. **Better and more defensible methods for measuring unbiased concentrations of agricultural PM are needed. Such methods can only be developed and proved using standard test methods in a controlled environment wind tunnel meeting EPA's test criteria.**

The performance characteristics of several TSP samplers, including a novel sampler developed by the PI, when sampling large particles typical of agricultural aerosols will be characterized in a wind tunnel meeting EPA's performance criteria described in 40 CFR 53 Subpart D. Improved methods for characterizing sampler effectiveness for large particles that were developed in the PI's laboratory will be employed to improve the quality of previously collected data. The accuracy of results obtained by subsequent particle size analyses will also be evaluated.

The results of this research will include improved sampler performance information for TSP samplers when sampling aerosols characteristic of agricultural sources and will provide the information necessary to evaluate the accuracy of PM_{10} concentrations determined using a combination of TSP sampling and particle size analysis.

Proposal Narrative

Agricultural researchers have observed an “oversampling bias” in PM_{10} concentrations measured using FRM samplers. Under previous SAQI funding, the PI demonstrated that non-trivial fractions (~3%) of large particles (20-25µm) penetrate the pre-collector of FRM PM_{10} samplers, leading to substantial bias relative to EPA’s “ideal” PM_{10} sampler when sampling large particles such as those emitted by agricultural operations.

To overcome these sampler bias issues, methods have been developed to calculate “true” PM_{10} and $PM_{2.5}$ emissions using PM samples collected with LVTSP samplers combined with particle size characterization of the collected samples. To determine “true” PM_{10} emissions, a lognormal fractional efficiency curve with a cutpoint of 10µm and a slope of 1.5 has been applied to the collected TSP data (fig. 1). This “oversampling bias” of FRM samplers leads to inequitable over-regulation of agricultural industries by overstating agriculture’s PM_{10} emissions.

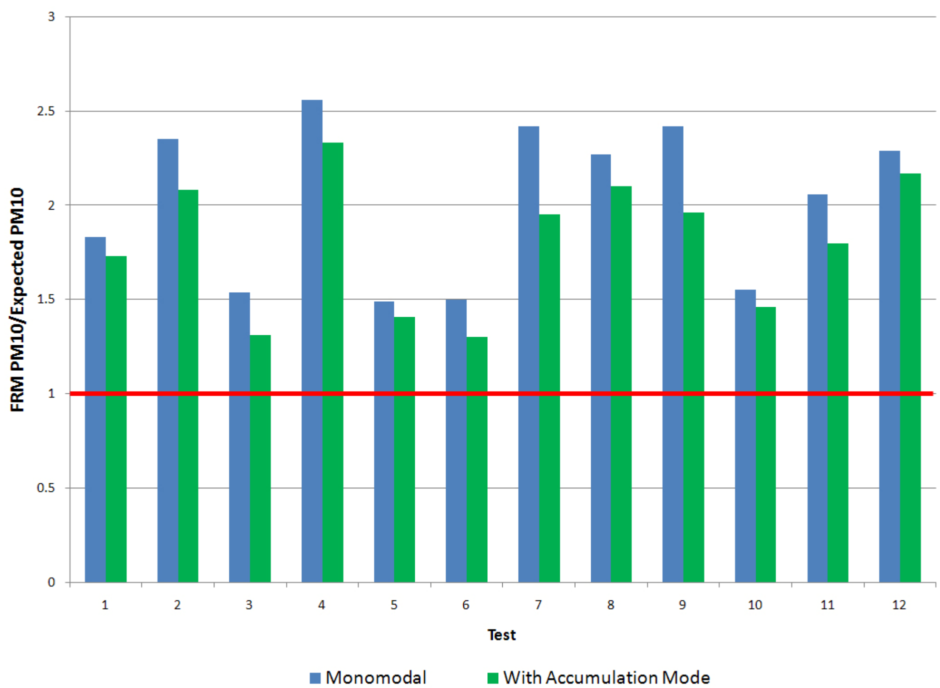

Figure 1. Ratio of PM_{10} concentrations measured downwind of a cotton gin with an FRM sampler to that measured using a TSP sampler and particle size analysis (Buser et al., 2008). Blue bars indicate a monomodal PSD; green bars indicate concentrations when the accumulation mode from the 1996 PM Criteria Document is included.

Scientists at EPA have argued that ambient particle compositions cannot be reconstructed using the techniques employed by Buser et al. (2008) and others. Under previous SAQI funding, the PI demonstrated that the performance of the LVTSP samplers employed in many previous studies is dependent on ambient wind speed (table 1), which likely biases both measured concentrations of TSP (negative bias) and the measured fraction of TSP that is PM_{10} (positive bias). The wind tunnel in which the PI evaluated these samplers meets all of the requirements for a wind tunnel to test FRM PM_{10} inlets under 40 CFR Part 53 Subpart D, giving results improved credibility over similar experiments conducted in ambient environments. Furthermore, under previous SAQI funding, the PI has validated the performance of the wind tunnel and has produced performance reports for PM_{10} inlets that meet EPA's data requirements and have been approved by aerosol scientists from EPA.

Table 1. Estimated cutpoints for LVTSP sampler.

Wind Speed (kph)	Cutpoint (μm)
2	>18
8	15-18
24	6.1

In addition to questions of aspiration, EPA scientists have questioned whether methods utilized to disperse filtered aerosols for measurement bias results. **Better and more defensible methods for measuring unbiased concentrations of PM from agricultural sources are needed.**

Shrouded Probe Aerosol Sampler

The shrouded probe (fig. 2) is a unidirectional sampling inlet used for extractive sampling of particulates from stacks and ducts that has superior performance characteristics relative to sharp-edged, isokinetic extraction nozzles commonly used today. Based on preliminary fluid dynamics modeling, the shrouded probe could be adapted to provide superior ambient TSP sampling performance relative to existing LVTSP samplers, especially for large particles, such as those emitted by agricultural operations, and for high ambient wind speeds.

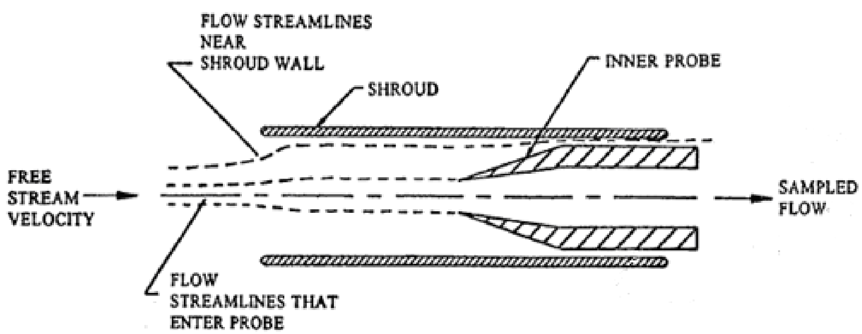

Figure 2. Cross-section view of a shrouded probe (Chandra and McFarland, 1995).

Objectives

The goal of the proposed research is to develop better methods for determining unbiased concentrations of PM from agricultural sources. Specific objectives of the proposed research include:

- Evaluate the performance of three existing LVTSP sampler designs to in a wind tunnel meeting all specifications for Subpart D testing of ambient aerosol inlets
- Demonstrate the performance of a novel ambient TSP sampler designed by the PI based on the shrouded probe concept
- Evaluate biases that may be introduced to TSP samples when filtered particles are dispersed for particle size analysis.

Results of this project should provide the data necessary to address concerns by EPA scientists about improved methods of measuring PM from agricultural sources.

Methods

Objective 1. Evaluate the performance of existing LVTSP samplers in a wind tunnel.

The performance of three existing LVTSP sampler inlets will be evaluated in a wind tunnel in the PI's lab that conforms to the requirements of 40 CFR 53 Subpart D. Evaluated inlets will include:

- The TAMU LVTSP sampler described by Wanjura et al. (2005)
- The "rain cap" LVTSP inlet described by Kenny et al. (2005)
- The BGI Standard TSP Inlet, which is a FRM PM10 inlet without the impactor

This wind tunnel is one of only a three wind tunnels available for Subpart D testing in the world (two of which are in the PI's laboratory and the third which belongs to the Department of Homeland Security). Particles used to challenge the sampler will be generated using a Vibrating Orifice Aerosol Generator (VOAG), and sampler performance for will be evaluated at three wind speeds (2, 8, and 24 km/h) according standard test methods. Improved methods for analyzing the penetration of large particles through the sampler inlet developed by the PI under previous SAQI funding will be employed, which will improve the confidence of results for particles larger than 15µm relative to previous inlet tests.

Sampling effectiveness curves will be developed for each inlet. The ideal TSP inlet would have sampling effectiveness curves that are unaffected by ambient wind speed and are characterized by near-100% penetration for particles up to ~40um in diameter. The implications of results for both future aerosol sampling and previous published results will be reported.

Objective 2. Demonstrate the performance of a novel ambient TSP sampler.

In order to assess the different modes of operation possible for the shrouded probe, air flow through and around a combination of 12 shroud designs and 12 inner nozzle designs (144 total shrouded probe models) will be modeled using ANSYS CFX 13.0 (Ansys Inc.; Canonsburg, PA). Each of the 12 shrouds and 12 nozzles will be machined to be interchangeable such that all 144 shrouded probes can be assembled from 24 parts. Velocity profiles will be developed for each shrouded probe using a thermal anemometer (IFA 300; TSI Inc.; Shoreview, MN) available in the PIs' laboratory. Once the velocity profile is adequately established for each probe and the fluid mechanics model is validated, the existing empirical model to predict aspiration efficiency of shrouded probes (McFarland et al., 1989) will be applied to each of the 144 nozzle combinations to predict inlet aspiration performance. The most promising nozzles will be tested in the wind tunnel, where predicted aspiration will be compared to empirical data collected using fluorescently-tagged, monodisperse aerosols generated in the wind tunnel at several wind speeds and yaw directions.

The aspiration efficiency of each of shrouded probe sampler for particles ranging from 3 to 25µm will be measured using procedures similar to those described in 40 CFR Part 53 Subpart D for PM_{10} sampler validation. This procedure requires a triplicate testing of sampler performance at multiple particle sizes under varied free-stream velocities. Results will include complete sampler aspiration curves (one per wind speed) for each inlet tested (e.g. fig. 3).

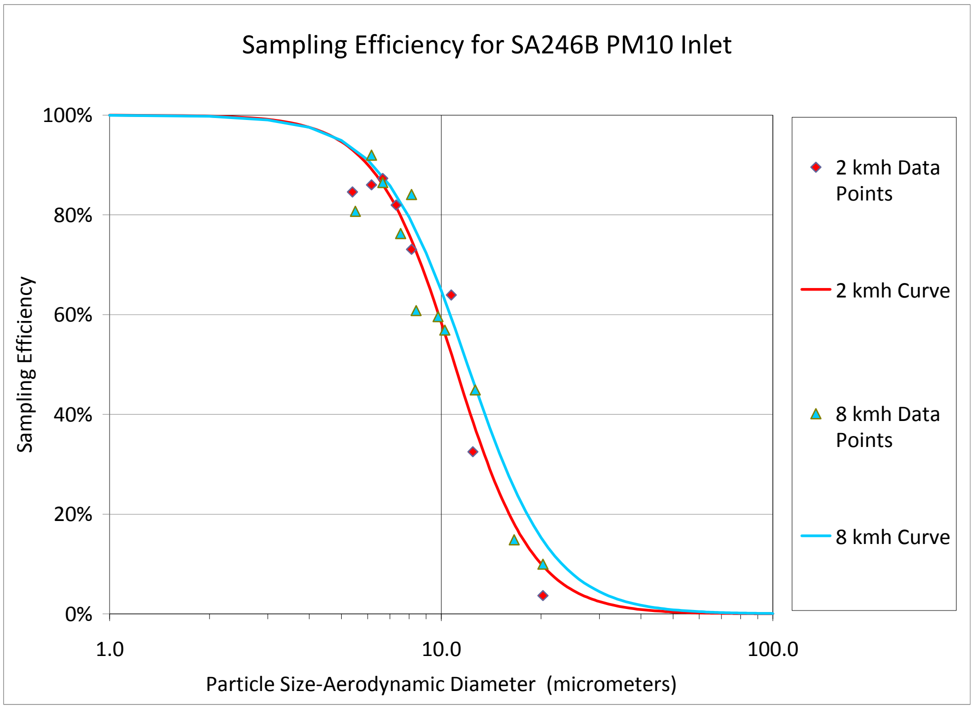

Figure 3. Example sampling efficiency curve.

Objective 3. Evaluate biases that introduced when analyzing PSDs of captured particles.

One of the objections to previous research employing TSP sampling combined with post-sampling PSD analysis has been a lack of validation that the PSD of dust extracted from the filter is representative of the ambient PM. Aspiration issues affecting the representativeness of samples will be addressed under Objectives 1 and 2. Post-sampling analysis will be addressed using an apparatus to entrain particulates with known shape, density, and refractive index in an airstream to be captured on filter media.

Dust will be fed into the system using a Wright Dust Feeder II (BGI Inc.) available in the PI's laboratory. The feed-rate of dust will be set to give an average concentration to obtain lightly (57 µg/cm^2, which is equivalent to 1 mg on a 47 mm filter), and heavily (171 µg/cm^2, which is equivalent to 3 mg on a 47 mm filter) loaded filters. The particle size distribution of the particulate collected on each filter will be determined by two well-established techniques: Electrical Sensing Zone (Multisizer 3 Coulter Counter) and Laser Diffraction (Malvern Mastersizer 2000).

Particle size results of dust analyzed with each of these methods will be compared to PSDs of parent materials, which will include the materials shown in table 2.

Table 2. Properties of test particulates – Equivalent Spherical Diameter.

	MMD (µm)	GSD	Density (g/cm^3)	% PM_{10}	% $PM_{2.5}$
A1 Ultrafine ARD	3.79	1.63			
A2 Fine ARD	8.68	1.72			
Limestone	7.0	1.71	2.62	73.8	3.0
Cerestar Starch	15.1	1.33	1.26	13.0	1.4

Deliverables and Timeline

Results of proposed experiments under Objective 1 will be submitted to Robert Vanderpool, an Aerosol Scientists with EPA's Office of Research and Development with whom the PI will work collaboratively to ensure that results are accepted by EPA. The report will also be submitted for peer review and publication in a high-impact journal such as *Aerosol Science and Technology*.

Table 3. Project timeline.

Task	Year 1				Year 2			
	Qtr. 1	Qtr. 2	Qtr. 3	Qtr. 4	Qtr. 1	Qtr. 2	Qtr. 3	Qtr. 4
Objective 1. Evaluate the performance of existing LVTSP samplers in a wind tunnel.								
Evaluate existing TSP samplers	X	X	X	X	X			
Objective 2. Demonstrate the performance of a novel ambient TSP sampler.								
Build shrouded probe samplers		X	X					
Model shroud velocity profiles				X	X			
Evaluate shrouded sampler					X	X	X	X
Objective 3. Evaluate biases that may be introduced when analyzing PSDs of captured particles.								
Build test stand			X	X	X			
Evaluate filter PSDs					X	X	X	X

Individual Responsibilities

Brock Faulkner (PI) is an expert in PM sampling and characterizing air pollutant emissions from agricultural sources. Dr. Faulkner will coordinate the overall project, including overseeing experiment planning, data analysis, reporting, and overseeing the post-doctoral scientist (Gang Sun), graduate student (Ge Li) and Research Assistant (Mathew Shimek). Dr. Faulkner has 6+ years of experience in agricultural air quality, specialized in emissions characterization, mitigation, and fate. Dr. Faulkner has served as PI/Co-PI on more than $3.1 million in contracts and grants. Dr. Faulkner also currently serves as an officer of the ASABE Environmental Air Quality Committee and on the USDA Agricultural Air Quality Task Force and EPA Science Advisory Board Panel for Estimating Air Emissions from Animal Feeding Operations.

Potential for Leveraging Resources

Previous air quality initiative funding has been leveraged by the PI to obtain over $1.6M in additional funding from multiple sources, including USDA ($1.25M), the Almond Board of California (>$180,000), the Texas Soil and Water Board (>$165,000), National Institute of Health ($84,000), and the Cotton Foundation ($30,000). The PI is currently engaged with several sampler development companies developing and testing new samplers using protocols developed under previous SAQI funding, including Tisch Environmental ($30,000 currently and negotiating future projects), BGI and MetOne Instruments (currently negotiating future projects). EPA's Office of Research and Development has already committed ~$40,000 in in-kind equipment loans and ~$10,000 in staff time to assist execution of the proposed project. Additionally, BGI Incorporated has committed ~$10,000 in in-kind equipment loans. Future funding is expected to come from companies interested in development of new PM inlets. There has been a recent push towards smaller-scale PM samplers to reduce pump power for remote deployment. Proposals for use of the wind tunnel will also be submitted to EPA, NSF, and USDA for bioaerosol sampler evaluation and development of new sampling methods.

Budget

	FY 2014	FY 2015
Personnel		
Principle Investigator (Brock Faulkner; 1 mo/yr)	$9,409	$9,691
Technician (Matthew Shimek; 2-3 mo/yr)	$7,570	$11,696
Post-Doctoral Researcher (Gang Sun; 6 mo/yr)	$21,000	$21,630
Graduate Student (Ge Li)	$19,200	$20,190
Equipment		
Anemometer Traverse	$21,500	$0
Materials		
Flow Meters	$2,000	$4,000
Materials for Shrouded Probes	$2,000	$1,000
Lab Expendables	$3,000	$6,000
Travel		
Professional Conference	$1,600	$1,600
Student Support		
Tuition and Fees	$8,712	$9,147
Total	**$99,991**	**$88,924**

A thermal anemometer (IFA 300; TSI Inc.; Shoreview, MN) is available in the PI's laboratory for developing velocity profiles in the shrouded probe, but a traverse for the anemometer will be necessary to precisely position the anemometer in a repeatable manner in order to develop accurate flow profiles as part of Objective 2.

William Brock Faulkner, Ph.D., P.E.

Assistant Professor
Biological and Agricultural Engineering Department, Texas A&M University

EDUCATION

Degree	*Institution*	*Major Field of Study*	*Dates*
Ph.D.	Texas A&M University	Biological and Agricultural Engineering	2008
M.S.	Texas A&M University	Biological and Agricultural Engineering	2006
B.S.	Texas A&M University	Agricultural Engineering	2004

PROFESSIONAL EXPERIENCE

Employer	*Position*	*Location*	*Dates*
Texas A&M University	Assistant Professor	College Station, Texas	2012
Texas A&M University	Research Assistant Professor	College Station, Texas	2008-2011
Texas A&M University	Research Associate	College Station, Texas	2006-2008

PREFESSIONAL AND SCIENTIFIC ORGANIZATIONS

USDA Agricultural Air Quality Task Force
EPA Science Advisory Board Panel for Review of Methodologies for Estimating Air Emissions from Animal Feeding Operations
American Society of Agricultural and Biological Engineers (ASABE)

HONORS AND AWARDS

2010	Member of team awarded Texas Environmental Excellence Award - Agriculture
2010	ASABE Texas Section Young Engineer of the Year
2004-2007	National Science Foundation Graduate Research Fellow
2004-2006	Regents Fellow – Texas A&M University

SELECT INVITED PRESENTATIONS

1. "Air Quality and Animal Agriculture" –Colorado Livestock Association Annual Convention (June 2008)
2. "Estimating $PM_{2.5}$ Emission Factors" –USDA Agricultural Air Quality Task Force (May 2009)
3. "An Evolving Case Study in Management of Reactive Nitrogen" - USDA Agricultural Air Quality Task Force (May 2009)
4. Rethinking Emissions from Cattle Operations" –EPA Office of Air Quality Planning and Standards (February 2010)
5. Improved Measurement of Particulate Matter (PM) from Animal Feeding Operations" – Continuing Professional Development course (September 2010)
6. Ammonia Regulation and the US Cattle Industry" - National Cattlemen's Beef Association (February 2011)
7. "Identifying BMPs for Reducing Ammonia Emissions from Livestock Production" – Colorado Livestock Association Annual Convention (June 2011)
8. "What's in the Air – And Why You Should Care" - Colorado Agriculture Air Quality Symposiums (February 2012)

SELECT CONSULTING

Client	*Subject*
Colorado Livestock Association	Air pollutant emissions, transport, modeling, monitoring, and deposition
Five Rivers Ranch Cattle Feeding	Evaluation of ammonia emissions monitoring plan for evaluation of best management practices
National Cattlemen's Beef Assoc.	Technical analysis of draft Policy Assessment Document for secondary NO_x/SO_x NAAQS

SELECT PEER-REVIEWED PUBLICATIONS

1. Borhan, M.S., S.C. Capareda, S. Mukhtar, **W.B. Faulkner**, R. McGee and C.B. Parnell. 2011. Greenhouse gas emissions from ground level area sources in dairy and cattle feedyard operations. *Atmosphere* 2(3): 303-329. doi: 10.3390/atmos2030303.
2. **Faulkner, W.B.**, D. Downey, D.K. Giles, and S.C. Capareda. 2011. Evaluation of particulate matter abatement strategies for almond harvest. *Journal of the Air and Waste Management Association* 61: 409-417.
3. **Faulkner, W.B.**, L.B. Goodrich, V.S.V. Botlaguduru, S.C. Capareda, and C.B. Parnell. 2009. Particulate matter emission factors for almond harvest as a function of harvester speed. *Journal of the Air and Waste Management Association* 59: 943-949.
4. **Faulkner, W.B.**, B.W. Shaw, and T. Grosch. 2008. Sensitivity of two dispersion models (AERMOD and ISCST3) to input parameters for a rural ground level area source. *Journal of the Air and Waste Management Association* 58: 1288-1296.
5. **Faulkner, W.B.** and B.W. Shaw. 2008. Review of ammonia emission factors for United States animal agriculture. *Atmospheric Environment* 42(27): 6567-6574.
6. **Faulkner, W.B.**, M.D. Buser, D.P. Whitelock, and B.W. Shaw. 2008. Effects of cyclone diameter on performance of 1D3D cyclones: cut point and slope. *Transactions of the ASABE* 51(1): 287-292.
7. **Faulkner, W.B.**, J.J. Powell, J.M. Lange, B.W. Shaw, R.E. Lacey, and C.B. Parnell. 2007. Comparison of dispersion models for ammonia emissions from a ground level area source. *Transactions of the ASABE* 50(6): 2189-2197.
8. **Faulkner, W.B.**, B.W. Shaw, and R.E. Lacey. 2007. Coarse fraction aerosol particles: theoretical analysis of rural versus urban environments. *Applied Engineering in Agriculture* 23(2): 239-244.

WHITE PAPERS

1. **Faulkner, W.B.** 2011. Potential impacts of changes in NAAQS for particulate matter. White Paper written on behalf of the Colorado Livestock Association to inform producers and policy makers about the impact of proposed changes to PM regulations.
2. **Faulkner, W.B.**, B.W. Shaw, and S. Krupa. 2009. Particulate matter (PM) and agricultural air quality: a summary of the current status and research needs. White Paper submitted to the USDA Agricultural Air Quality Task Force (AAQTF) at the request of the AAQTF Air Quality Standards Subcommittee.

Interim Progress Report for Previous Funding

Characterization of Large Particle Transmission in FRM PM_{10} Samplers: Impact on PM Regulation in Rural Environments

The goal of the previously-funded SAQI research was to characterize the performance of FRM PM_{10} samplers for large particles to determine whether a significant mass of particles that would not penetrate the ACGIH thoracic curve is able to deposit on the filter of an FRM PM_{10} sampler. In this manner the adequacy of the FRM sampler for protecting public health and welfare in rural environments may be more accurately assessed. Improved methods for assessing sampling efficiency of large particles such as those emitted from agricultural operations were developed and implemented to develop a performance curve for the FRM PM_{10} inlet at a wind speed of 8 km/h. Results of the sampler evaluation along the “sharp” part of the performance curve compared well with those reported by Tolocka et al. (2001) for a similar inlet, and the sampler passed the criteria required for certification as a FRM sampler when tested at 8 km/h. Using the improved methods for large particle analysis, sampling effectiveness values for particles with nominal diameters of 20 and 25μm exceeded 3% in the present study and were statistically different than “zero” ($p < 0.05$) but were not of the order of magnitude estimated by Buser et al. (2008). However, given the relative mass of 20-25μm particles compared to 5-10μm particles, 3% penetration of these particles can lead to non-trivial, “oversampling” biases in PM_{10} concentrations measured using FRM samplers.

Research Accomplishments

- Developed improved protocols for analyzing the sampling effectiveness of size selective samplers for large particles such as those characteristic of agricultural operations
- Developed performance curve for SA246 PM_{10} inlet at a wind speed of 8 km/h (fig. 1)
- Identified non-trivial penetration of large particles in the 20-25μm size range
- Submitted 8 km/h report, including observations of large particle penetration to Dr. Robert Vanderpool of EPA-ORD for review and subsequently addressed his concerns regarding these findings, furthering opportunities for future research efforts addressing sampling of agricultural aerosols

Successes

- Developed improved methods of measuring large particle penetration of sampler inlets
- Worked extremely cooperatively with Robert Vanderpool of EPA to develop data collection and analysis procedures and further the conversation regarding sampling biases when measuring concentrations of agricultural aerosols

Setbacks

- Consistent and enduring generation of large particles using the VOAG as prescribed by 40 CFR 53 Subpart D proved to be a substantially greater challenge than anticipated, which slowed project progress for several months
- Significant experience gained in particle generation and sampler evaluation was lost half-way through Year 2 of the project when the primary graduate student on the project accepted full-time employment before completing the project.

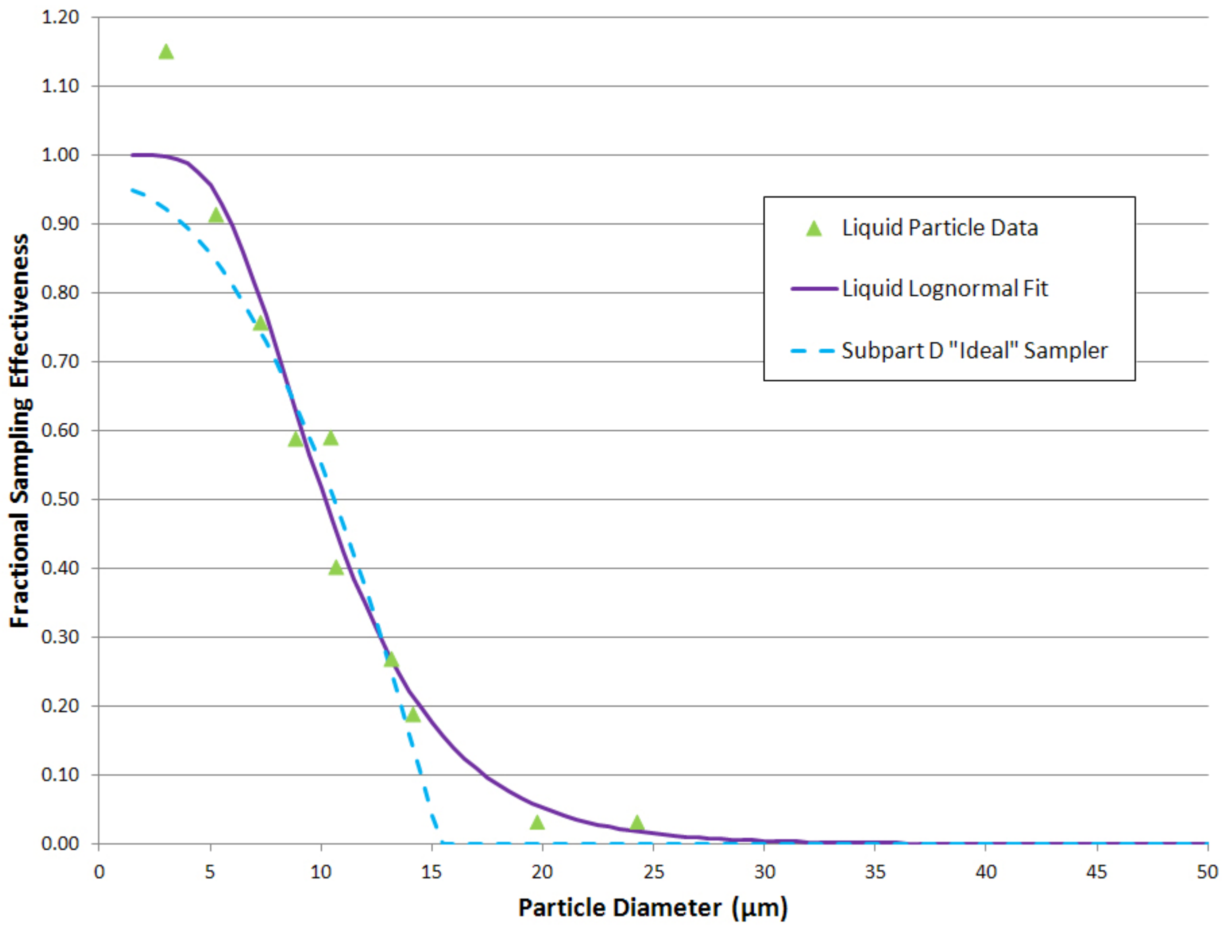

Figure 1. Liquid particle effectiveness data, lognormal performance curve with multiplet correction, and "ideal sampler" performance curve from 40 CFR Part 53 Table D-3).

Major Findings

- Non-trivial penetration (~3%) of large particles occurs in FRM PM_{10} samplers that meet the performance requirements of 40 CFR 53 Subpart D.
- The penetration of large particles can lead to oversampling bias when samplers are operated in the presence of aerosols characterized by large particles such as agricultural dust emissions, even when samplers are meeting FRM performance requirements.

Anticipated Impacts to Stakeholders

Finds of the present study should significantly further on-going conversations with EPA regarding challenges of measuring agricultural aerosols. The PI is in the process of communicating data generated from this project to Dr. Christie Sayes, Program Manager at RTI International, who is interested in health effects of aerosol exposure and will assist with understanding the implications of present research to public health indices for agricultural workers and rural communities.

Expenditures

Category	Expenditures to Date
Salaries and Wages	$120,107
Supplies	$10,477
Equipment	$28,618
Service and Repairs	$5,349
Travel	$4,953
Total	**$169,504**

Proposals Generated as a Result of Funding

Sponsor	Amount
Funded	
Cotton Foundation	$20,000
Tisch Environmental	$30,000
Pending	
Nuclear Regulatory Commission	$1.12M
National Science Foundation	$201,979
Cotton Foundation	$20,000
Under Development	
BGI, Inc.	TBD
MetOne Instruments	TBD
Not Funded	
National Science Foundation	$199,956