PM Sampling: Collaborative Study Between Texas A&M and U.S. EPA

EPA's Presentation and Interpretation of Test Results

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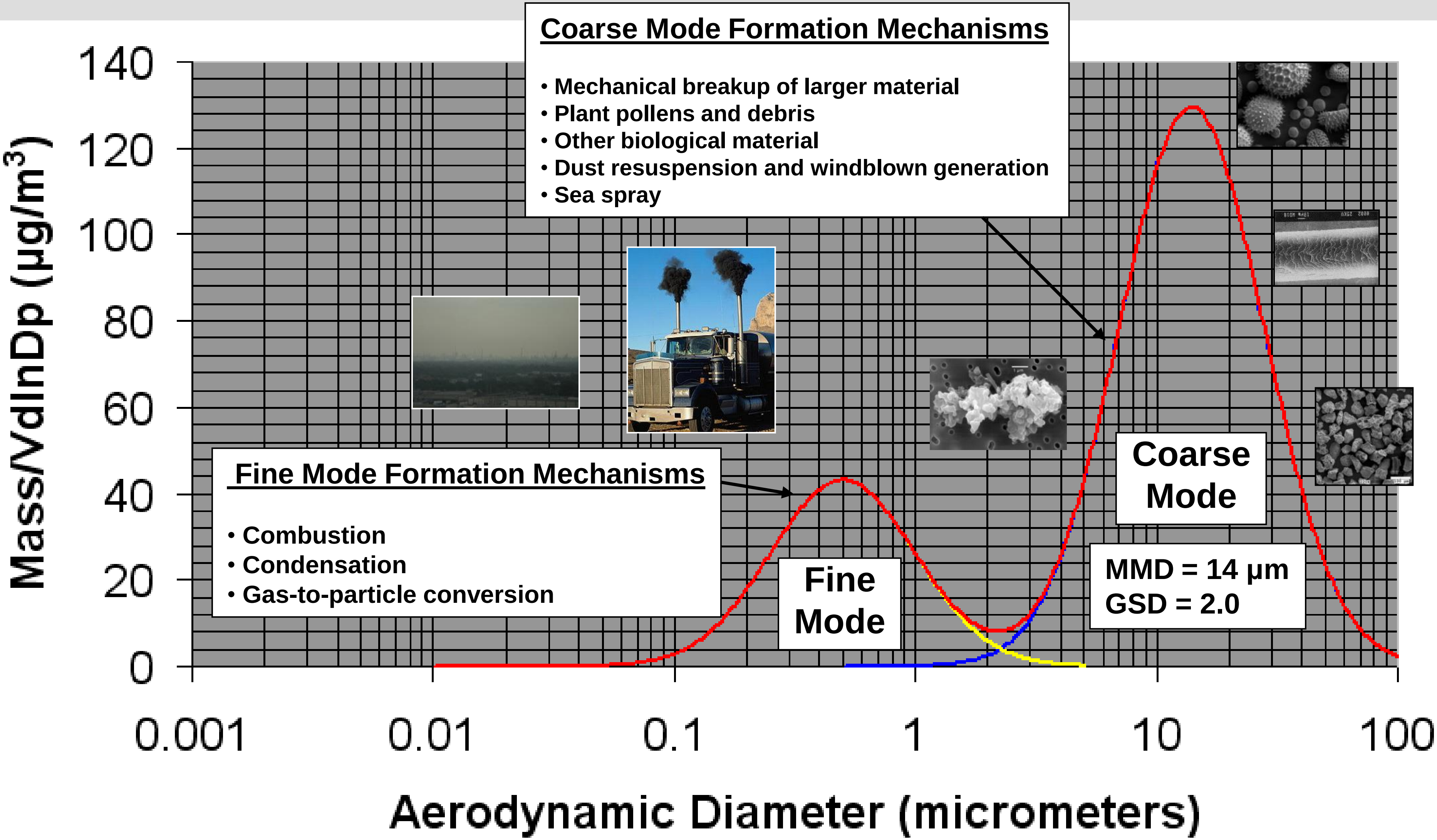
Presentation Outline

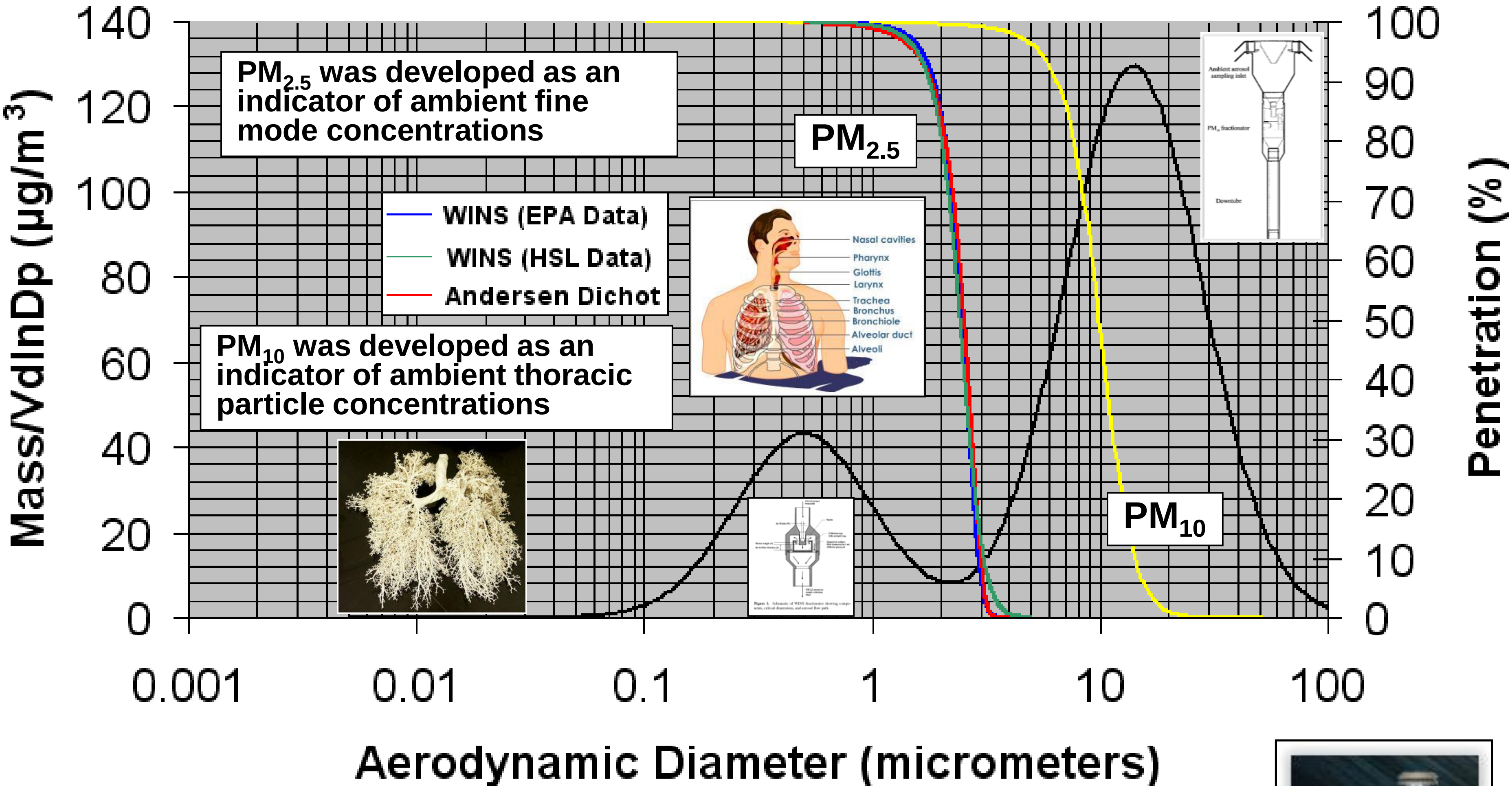
- Background regarding particulate matter (PM) sampling and the Ag concerns regarding “oversampling” by EPA’s FRMs
- Key questions raised during Ag/EPA discussions
- Study Plan developed to address key questions
- Texas A&M’s wind tunnel evaluation of EPA’s PM_{10} inlet
- Texas A&M’s and EPA’s wind tunnel evaluation of the LVSTP inlet
- Summary

Characteristics of Ambient Particulate Matter

Ambient aerosols are bimodal in size and the relative modal concentrations can vary with site, season, and local activity. Modes are typically lognormal in shape.

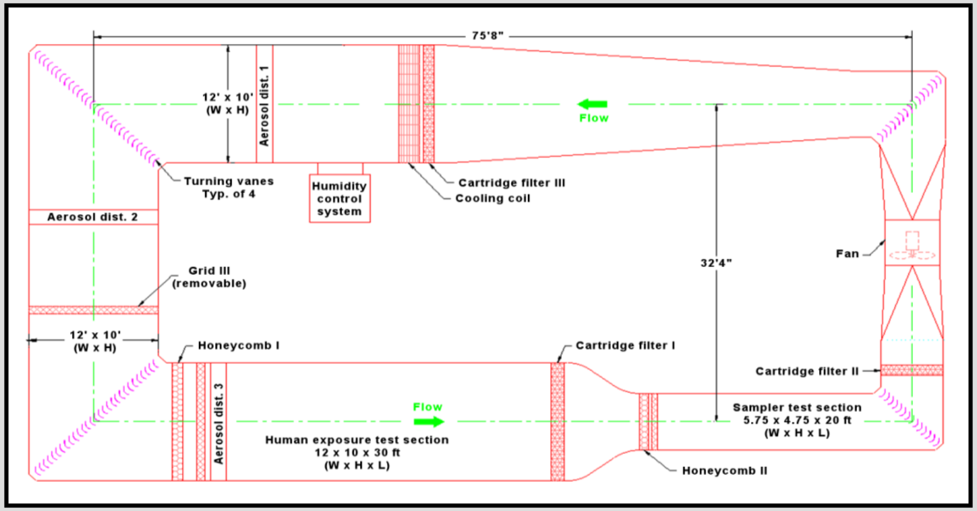


$PM_{2.5}$ and PM_{10} Method Development



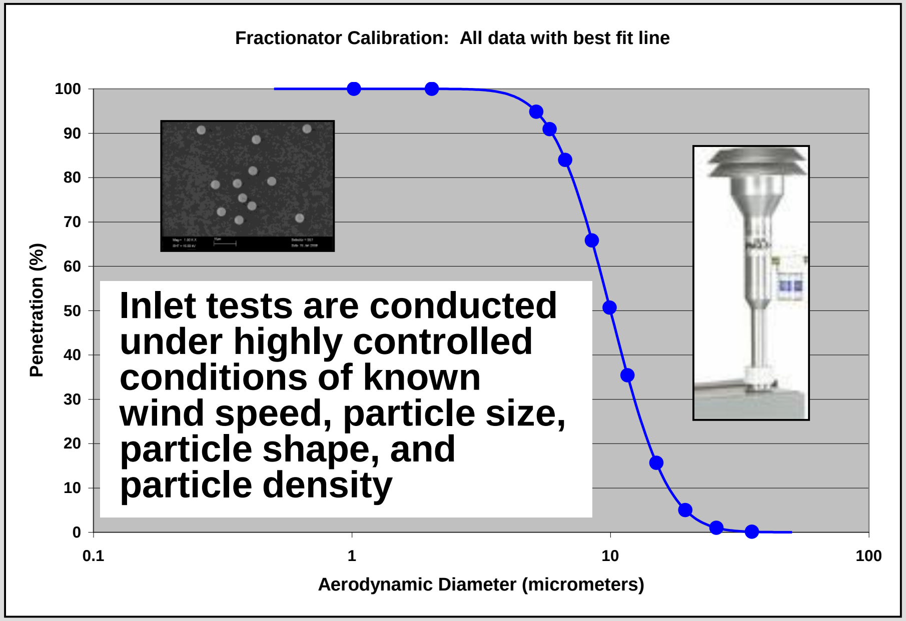
EPA's $PM_{2.5}$ and PM_{10} method development efforts were <u>very strongly</u> peer reviewed and have been supported during subsequent PM NAAQS reviews and independent evaluations.

Wind Tunnel Evaluation of Size Selective Performance



EPA'S Aerosol Wind Tunnel

The size-selective performance of PM_{10} samplers must be demonstrated in an aerosol wind tunnel at wind speeds of 2, 8, and 24 km/hr, using monodisperse aerosols from 3 to 25 µm diameter.



Acceptance Criteria (2, 8, & 24 km/hr)

Dp_{50} cutpoint = 10 ± 0.5 µm

Solid vs. liquid (25 µm) = within 5%

Mass measurement accuracy = ± 10%

Example Ag Industry Publication

LVTSP Inlet (no internal fractionator)

EPA's PM_{10} Inlet with internal fractionator

Results of cotton gin field studies involving collocating the LVTSP inlet (with "True" PSD analysis) versus EPA's PM_{10} inlet

From Buser, et al., 2008. Transactions of the ASABE, Vol. 51(2): 695-702.

Abstract

"Recent work at a south Texas cotton gin showed that … **the cutpoint and slope of the FRM PM10 sampler shifted substantially and ranged from <u>13.8 to 34.5 µm</u>** ***and from 1.7 to 5.6, respectively, when exposed to large PM as is characteristic of agricultural sources."***

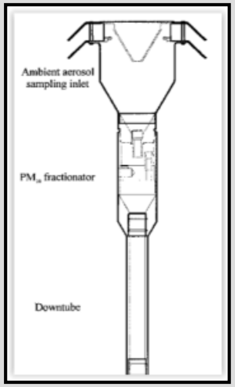
"These shifts in the cutpoint and slope of the FRM PM_{10} sampler resulted in overestimation of true PM_{10} concentrations by 145% to 287%."

MMD (µm)	GSD	Dust Conc. (µg/m^3)	"True" PM_{10} (µg/m^3)	FRM PM_{10} (µg/m^3)	Estimated "Oversampling"	Estimated PM_{10} Cutpoint (µm)
13.6	2.3	1,385	494	1,099	122%	32.6

In these collocated field studies, "True" PM_{10} is used as the measure of truth upon which to judge the accuracy of EPA's PM_{10} reference method PM_{10} inlet

Three Key Questions

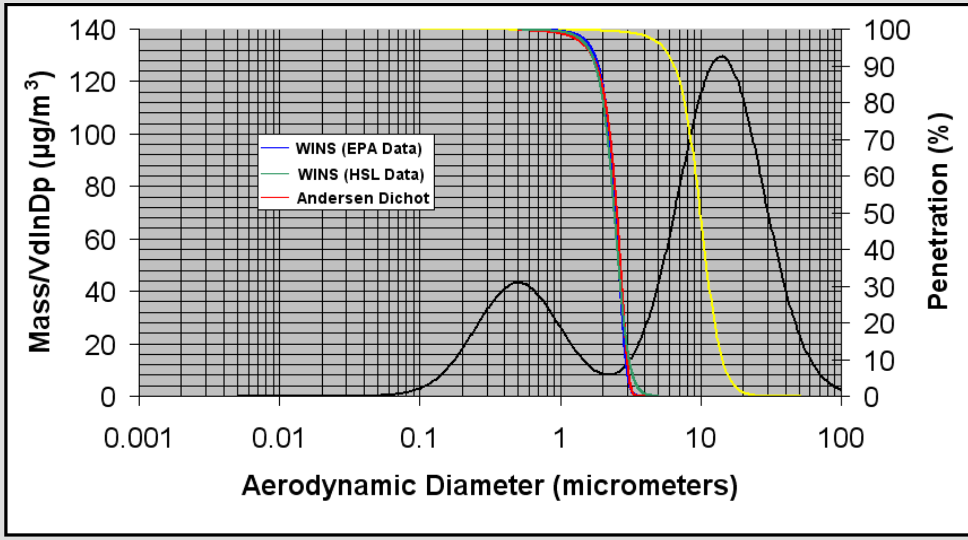
Sample No.	"True" PM_{10} (μg/m^3)	EPA's FRM PM_{10} (μg/m^3)	"True"/EPA	EPA's "Oversampling"	Estimated PM_{10} Cutpoint (μm)
1	642	1,152	0.56	79%	23.1
2	294	687	0.43	134%	29.6
6	260	383	0.68	47%	13.8
8	494	1,099	0.45	122%	32.6
11	284	557	0.51	96%	34.5
12	743	1,708	0.44	130%	22.9



1. Why does the "True" PSD approach of Buser et al. provides results so dramatically different than that of any other researcher?

2. Why do the "True" PM test results seem to vary during each test?

3. Is the PSD "True" method an accurate basis of comparison upon which to judge EPA's established reference methods?



$$\text{Oversampling} = (\text{EPA} - \text{"True"})/\text{"True"}$$

Comparison of "True" PSD method versus EPA's Reference Method

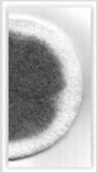
"True" PSD PM_{10} Procedure	EPA's FRM PM_{10} Procedure
1. Actively sample ambient air through LVTSP inlet at flow rate of 16.7 Lpm	1. Actively sample ambient air through FRM's PM_{10} inlet at flowrate of 16.7 Lpm
2. Collect all sampled particles on filter	2. Inertially size-separate each sampled particle based on its aerodynamic diameter and fractionator's size-selective curve based on thoracic criteria
3. Dissolve filter in electrically conductive aqueous solution, using ultrasonic method and dispersant, if necessary, to extract particles from filter	3. Collect fractionated particles on preweighed filter
4. Take aliquot of extracted solution and determine each particle's volume using a Coulter Counter	4. Post-weigh filter and determine PM_{10} mass concentration by dividing measured aerosol mass by sample air volume
5. Make assumption of each particle's density to convert each particle's volume to mass	
6. Make assumption of each particle's dynamic shape factor to convert equivalent spherical diameter and density into aerodynamic diameter	
7. Calculate mass of particles below 10 µm using a Step Function, rather than the actual PM_{10} curve	
8. Estimate PM_{10} mass concentration by dividing the less than 10 µm aerosol mass by sample air volume	

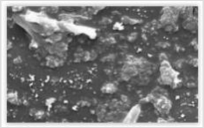
EPA's Concerns About PSD "True" Method

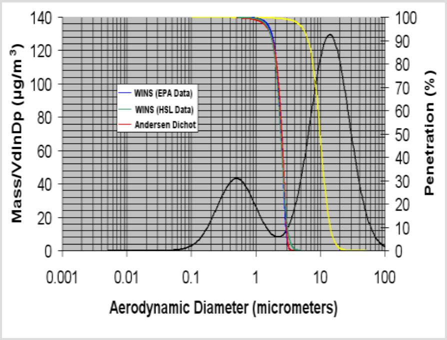
- **The LVTSP inlet was not rigorously designed nor had its actual size selective performance ever been evaluated in an aerosol wind tunnel. The PSD method requires that the LVTSP sampler display 100% sampling efficiency independent of wind speed and particle size.**

LVTSP Inlet (no internal fractionator)

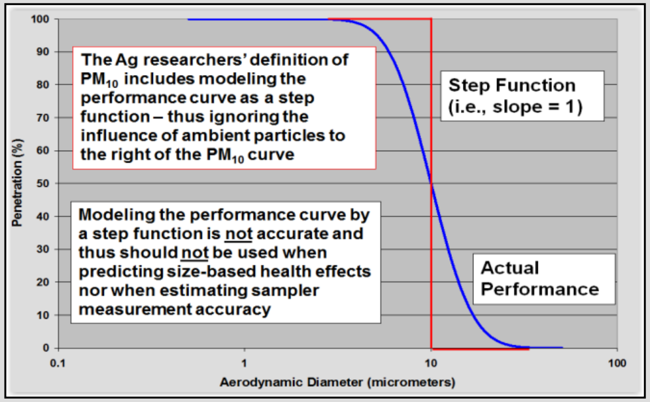
- **The PSD's "True" method of reconstructing the airborne particle size distribution requires the complete removal of accumulated particles from the filter, no loss of soluble aerosols, complete separation of captured particles into their original number and sizes, and assumptions of each particle's density and dynamic shape factor. The Coulter technique cannot detect particles less than approximately 2 to 3 μm so misses the entire fine mode of the ambient distribution.**







- **Definition of "True PM_{10}" assumes that PM_{10} is defined as a step function (which is <u>not</u> the case) and thus tends to underestimate airborne mass concentration in agricultural environments.**



PM Sampling Study Plan

Faulkner et al. (Texas A&M)

1) Resurrect Texas A&M's aerosol wind tunnel, develop effective operating protocols for their operation, and conduct independent wind tunnel evaluation of EPA's PM_{10} inlet as a function of aerodynamic particle size and wind speed

2) Conduct Texas A&M's wind tunnel evaluation of the LVTSP inlet

Vanderpool et al. (EPA)

1) Review "True" PM_{10} PSD method and investigate why the method concludes cutpoints of EPA's PM_{10} reference method varies from 13 to 33 µm

2) Compile previous wind tunnel test results of EPA's PM_{10} inlet

3) Conduct EPA's wind tunnel evaluation of the LVTSP inlet

- Mutual exchange of equipment, SOPs, and ideas towards reaching a consensus on key measurement issues

Brock Faulkner

- **His energy, enthusism, and committment were critical towards the success of the collaborative efforts between TAMU and EPA.**
- **Was personally committed to establishing a strong working relationship between the Agricultural community and EPA.**
- **Welcomed the mutual exchange of equipment, SOPs, and ideas towards reaching a consensus on key measurement issues.**
- **Successfully resurrected TAMU’s aerosol wind tunnel, developed operating protocols, supervised in-house staff, and oversaw all wind tunnel tests.**
- **Kept an open mind about technical issues, was respectful of EPA’s position, but always served as a strong representative for the Agricultural industry and his Department at TAMU.**
- **First researcher to successfully conduct a wind tunnel evaluation of a candidate high-volume $PM_{2.5}$ inlet per EPA’s 40 CFR Part 53 regulations**
- **Posthumous recipient of TAMU’s Early Career Alumni Award**

Texas A&M's Wind Tunnel Facility

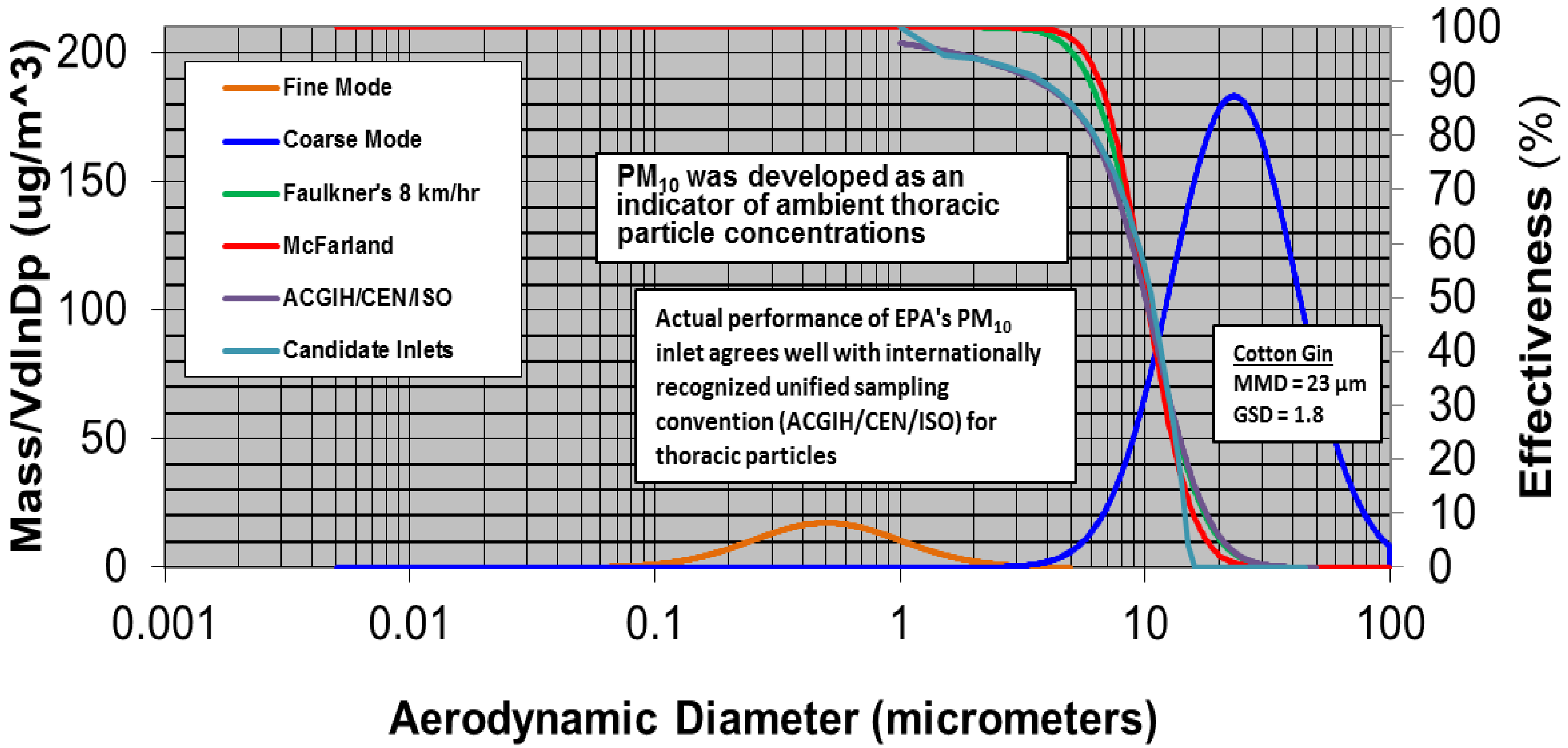
Isokinetic nozzles designed for determination of reference concentrations

Photograph of EPA's PM_{10} inlet inside of TAMU wind tunnel

Inter-Laboratory Test Results of EPA's PM_{10} Inlet
(Eight Separate Studies Conducted Over 30 years)

Performance of EPA's 16.7 Lpm PM_{10} Inlet						
Reference	Affiliation	Year	Aerosol Type	Dp_{50} Cutpoint (µm)		
				2 km/hr	8 km/hr	24 km/hr
McFarland & Ortiz	Texas A&M	1984	monodisperse	10.1	10.3	10.4
Hall et al.	Health & Safety Lab, England	1988	monodisperse	10.0	10.0	9.7
VanOsdell & Chen	RTI International/EPA	1990	monodisperse	9.8	10.0	9.9
VanOsdell	RTI International/EPA	1991	monodisperse	9.8	-	9.6
Tolocka et al.	EPA	2001	monodisperse	9.9	10.3	9.7
Chen & Shaw	Texas A&M	2007	polydisperse ATD	9.5	9.5	9.7
Lee et al.	Korea Institute of Standards	2013	monodisperse	10.0	10.3	10.0
Faulkner et al.	**Texas A&M**	**2013**	**monodisperse**	?	10.2	?
Acceptance criteria at all wind speeds = 10 ± 0.5 µm			Mean	**9.9**	**10.1**	**9.9**

Texas A&M's 2013 results confirm the strong historical inter-laboratory agreement during wind tunnel evaluation of the PM_{10} FRM inlet's size-selective performance. Cutpoint determinations are independent of wind speed.



Mass/VdlnDp (ug/m^3)
200
150
100
50
0
Fine Mode
Coarse Mode
Faulkner's 8 km/hr
McFarland
ACGIH/CEN/ISO
Candidate Inlets
PM10 was developed as an indicator of ambient thoracic particle concentrations
Actual performance of EPA's PM10 inlet agrees well with internationally recognized unified sampling convention (ACGIH/CEN/ISO) for thoracic particles
Cotton Gin
MMD = 23 µm
GSD = 1.8
100
90
80
70
60
50
40
30
20
10
0
Effectiveness (%)
0.001
0.01
0.1
1
10
100
Aerodynamic Diameter (micrometers)

Inter-Laboratory Comparison of Effectiveness Results for 20 µm and 25 µm Particles

	20 Micrometer Effectiveness			25 Micrometer Effectiveness		
	2 km/hr	8 km/hr	24 km/hr	2 km/hr	8 km/hr	24 km/hr
McFarland & Ortiz	0.1%	1.0%	0.9%	-	-	-
VanOsdell	-	-	-	2.3%	0.3%	3.1%
Hall et al.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tolocka et al.	0.0%	1.6%	0.0%	0.1%	0.2%	0.0%
Mean	**0.0%**	**0.9%**	**0.3%**	**0.8%**	**0.2%**	**1.0%**
Faulkner et al.	**0.5%**	**3.4%**	**5.4%**	**0.0%**	**3.5%**	**4.0%**

Texas A&M's large particle evaluation of the EPA PM_{10} inlet were not consistent with those obtained during four previous wind tunnel studies and will over-estimate the influence of large particles on PM_{10} concentration measurements.

How Well Does EPA's PM_{10} Inlet Agree with International Thoracic Sampling Conventions (ACGIH/CEN/ISO) When Measuring Agricultural Aerosols?

Agricultural Dust Type	Hypothetical Mass Conc. (µg/m³)	Size Distribution Parameters		Predicted PM_{10} Mass Concentration (µg/m³)		EPA/(ACGIH/CEN/ISO) Ratio
		MMD (µm)	GSD	EPA Inlet (Faulkner Curve)	Unified ACGIH/CEN/ISO Convention	
Dairy	300	15	2.5	101	95	1.06
Cattle Feedyard	300	17	2.8	107	101	1.06
Almond	300	17	2.1	82	78	1.05
Cotton Gin	300	23	1.8	39	39	1.00
Broiler Housing	300	24	1.6	26	27	0.96
Cornstarch	300	20	1.4	31	33	0.94
Wheat	300	14.7	2.08	107	101	1.06
Corn	300	13.6	1.8	99	94	1.05
Rice	300	12.1	2.24	127	120	1.06
					Mean =	1.03

Conclusion: The size-selective performance of EPA's PM_{10} inlet is in excellent agreement with international sampling conventions for thoracic aerosols and shows no measurement bias for particles generated from a wide range of agricultural operations

Unlike for gaseous criteria pollutants, there exist no absolute standards for PM. For this reason, PM standards are based on the measurement method itself, which is strictly specified in EPA's regulations.

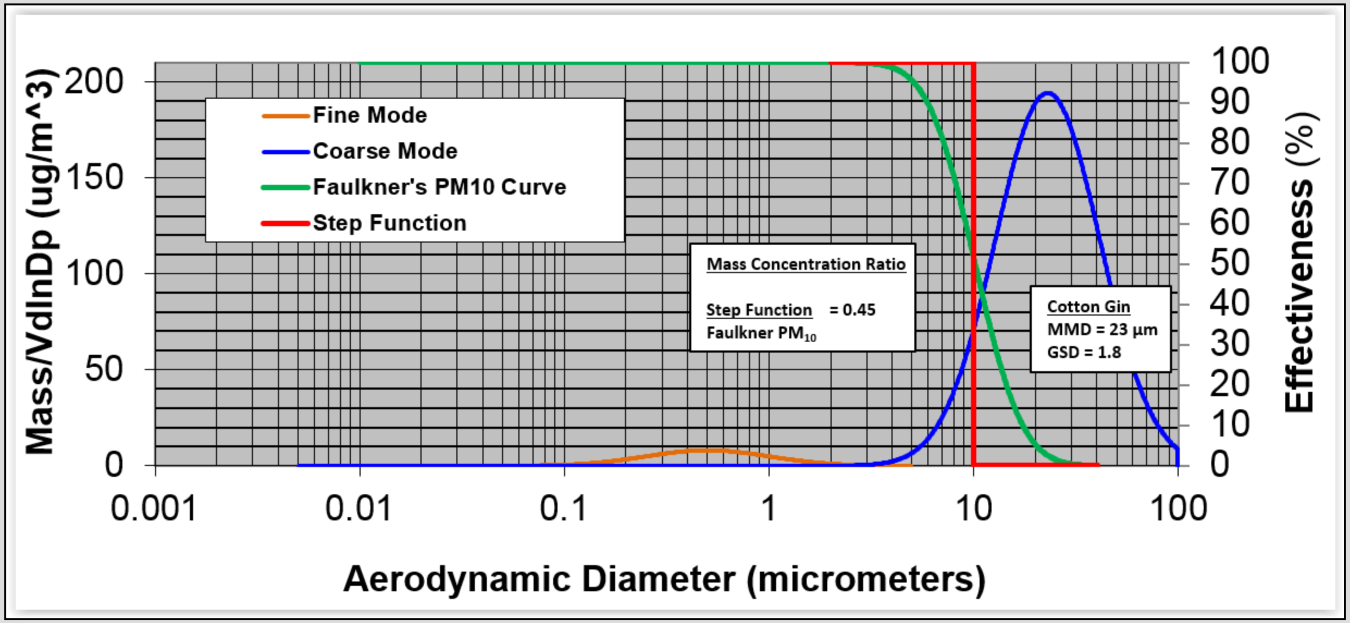
For NAAQS compliance purposes, PM_{10} is the mass concentration of ambient aerosol measured by an EPA-designated PM_{10} Federal Reference Method sampler which has been properly constructed, calibrated, sited, operated, and quality assured.

- Complete design specifications (dimensions, tolerances, and surface finishes) for PM_{10} and $PM_{2.5}$ inlets and fractionators are in the public domain and are published in the Federal Register

- Sampler operates at 16.7 aLpm based on continuous measurement of mass flow rate, ambient temperature, and ambient pressure

- Routine calibrations of flow rate, ambient temperature, ambient pressure, filter temperature, and leak rate are performed to ensure accurate sampling

- Specifications are provided for proper filter equilibration, handling, shipping, and weighing to ensure accurate quantitation of collected aerosol mass



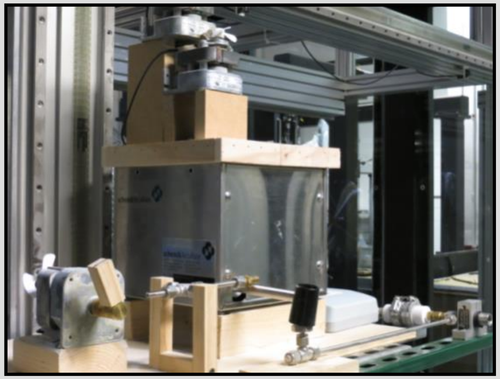
The PSD "True" PM_{10} method's use of the Step Function results in under-prediction of PM_{10} concentrations by 21% to 86% in agricultural environments compared to EPA's PM_{10} inlet

Agricultural Dust Type	Hypothetical Mass Conc. (µg/m³)	Size Distribution Parameters		Predicted PM_{10} Mass Concentration (µg/m³)		PSD/PM_{10} Ratio
		MMD (µm)	GSD	PDS's "True" PM_{10}	EPA's PM_{10}	
Dairy	300	15	2.5	90	114	0.79
Feedyard	300	17	2.8	82	106	0.77
Almond	300	17	2.1	68	92	0.74
Cotton Gin	300	23	1.8	23	51	0.45
Broiler Housing	300	24	1.6	9	39	0.23
Cornstarch	300	20	1.4	6	44	0.14

Note 1: All size distribution parameters are from Capareda et al. (2004)

Note 2: PM_{10} curves were generated using Faulkner's 8 km/hr wind tunnel data

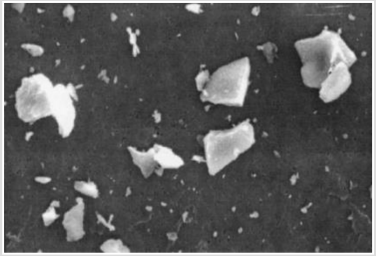
EPA's Recent Wind Tunnel Initiatives



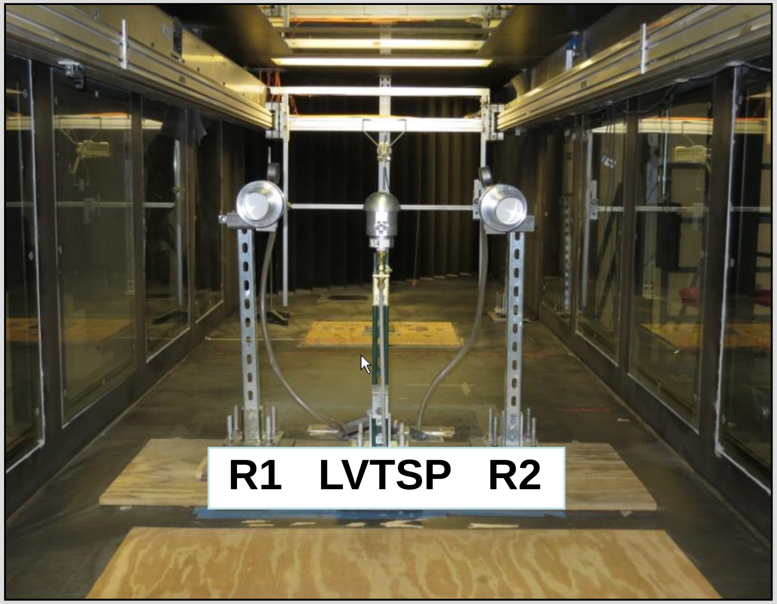
Apparatus used for dispensing, aerosolizing, and charge neutralizing calibration material into the aerosol wind tunnel

Isokinetic nozzles (114 Lpm, 90 mm filter) designed for determination of reference concentrations

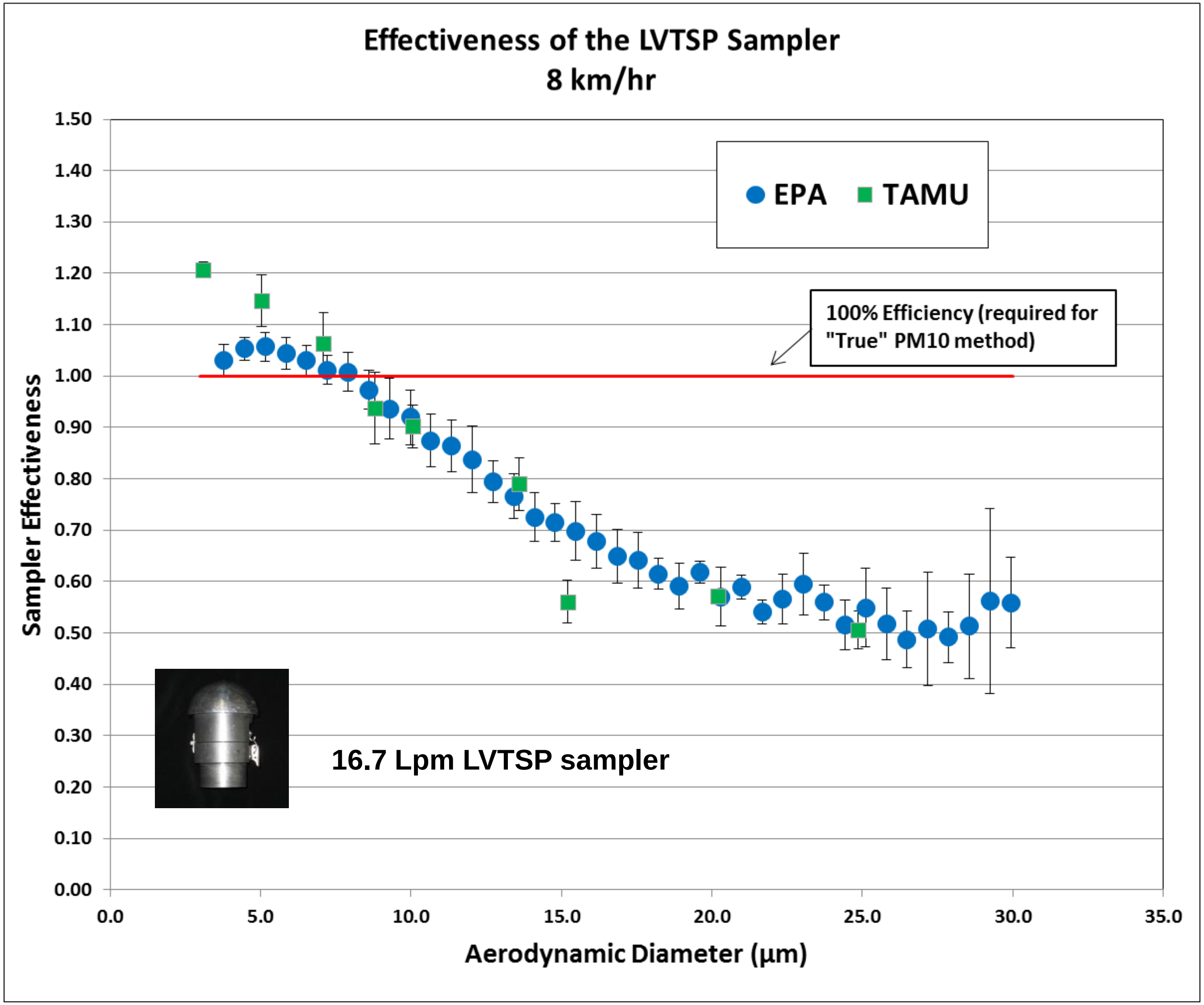
Multisizer IV Coulter Counter used for measuring the concentration and size distribution of collected test aerosols



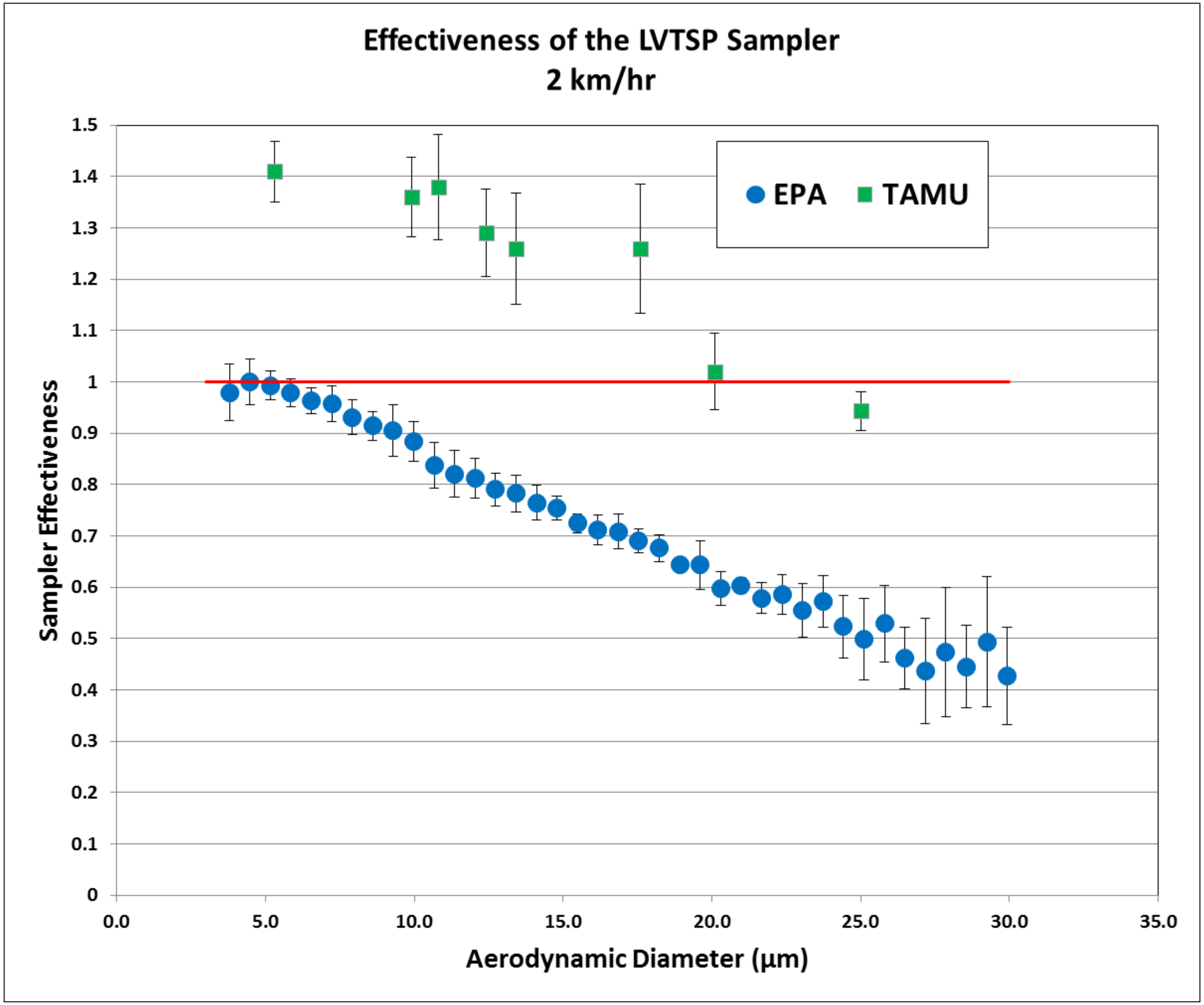
Polydisperse Arizona Test Dust (ATD) used during inlet evaluations

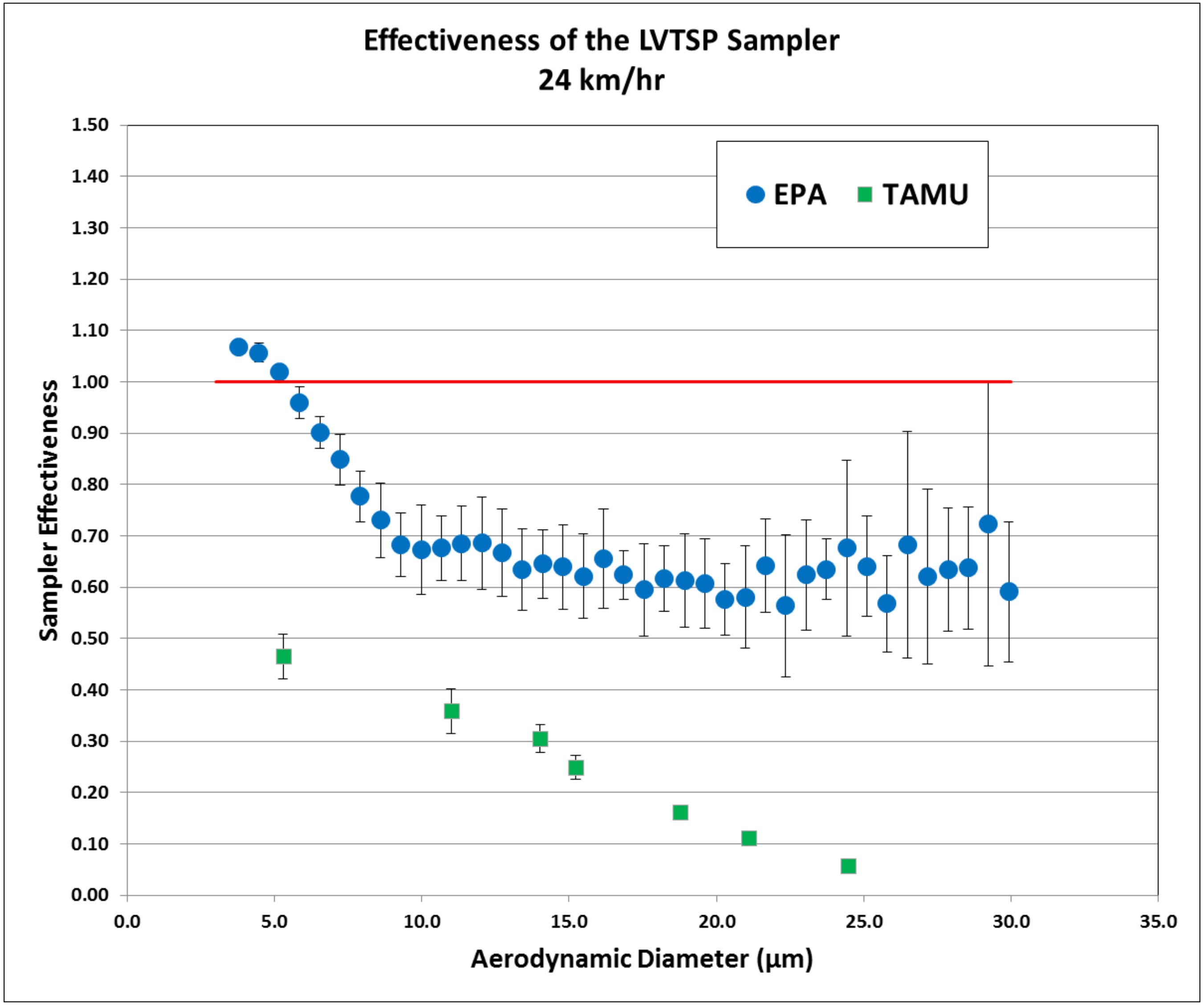


Photograph of EPA's wind tunnel test section during size selective evaluation of the LVTSP sampler



Compared to the performance of the 16.7 Lpm isokinetic sampler, the LVTSP sampler displays reduced collective efficiency with increasing particle size.


Effectiveness of the LVTSP Sampler
2 km/hr
EPA
TAMU
Sampler Effectiveness
Aerodynamic Diameter (µm)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0



Wind tunnel evaluation of the LVTSP sampler reveals that it's incapable of measuring total ambient PM concentrations independent of particle size. The LVTSP's size-selective performance also varies as a function of ambient wind speed.

In conjunction with other measurement problems associated with the PSD approach (extraction issues, particle measurement issues, and use of the Step Function), the variability in the LVSTP inlet's size selective performance makes the "True" PSD approach an inherently inaccurate method upon which to measure PM_{10} mass concentrations.

Summary and Conclusions

1. TAMU and EPA established a strong and mutually beneficial working relationship to address technical PM sampling issues, resulting in a mutual exchange of equipment, SOPs, and ideas. Both organizations devoted significant resources (time, effort, and funding) needed to achieve these goals.

2. TAMU and EPA successfully completed the experimental PM Methods Study Plan which was developed by the AAQTF, USDA, TAMU, and EPA.

3. TAMU's wind tunnel evalution of EPA's PM_{10} reference method inlet resulted in PM_{10} cutpoint determinations in very close agreement with 7 other wind tunnel studies. Test results were independent of wind speed, aerosol type, and aerosol concentration.

4. Although results from TAMU's and EPA's wind tunnel evaluations of the LVTSP inlet were not in complete agreement, collective results indicated that the performance of inlet declined sharply with increasing aerodynamic particle size and wind speed. At no wind speed did the LVTSP inlet demonstrate consistent measurement performance independent of particle size.

5. For the reasons discussed, the Buser et al. "True" PSD method of estimating ambient concentrations is <u>inherently negatively biased</u> and should <u>not</u> be used for evaluating the accuracy of EPA's PM reference methods.

Summary and Conclusions (cont)

6. Because the instantaneous actual size distribution of the ambient aerosol and wind speed is variable and unknown, the measurement bias of the LVTSP inlet cannot be mathematically corrected for during reduction and interpretation of data collected using the inlet.

7. EPA encourages use of approved, reference method PM samplers and analysis techniques to obtain test results which are scientifically valid and defensible.

8. Now that the PM Methods Study Plan has been successfully completed by TAMU and EPA, it is recommended that resources be directed from PM sampling issues towards problems of more importance to the Agricultural community.