Innovative Concepts – Phase I

In situ electrostatic separation of ambient $PM_{2.5}$ into source-specific fractions

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University Coal Research (UCR) Contractors Review Conference

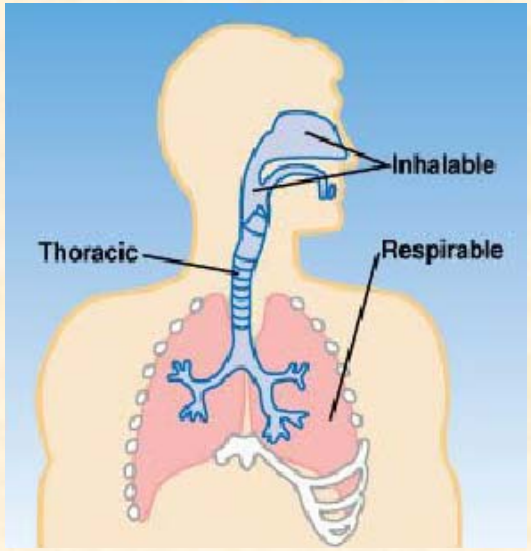
Pittsburgh, June 6, 2006

UK UNIVERSITY OF KENTUCKY

$PM_{2.5}$

What is $PM_{2.5}$?

Ambient airborne Particulate Matter with aerodynamic diameter less than 2.5 micrometers.



Why study $PM_{2.5}$?

The correlation between the concentration of airborne particulate matter $PM_{2.5}$ and human morbidity and mortality due to respiratory and cardiovascular disease is well established.

History of EPA's PM measurement

- 1971 – National Ambient Air Quality Standards (NAAQS) for TSP
- 1987 – Revised standards to PM_{10} - 150 $\mu g/m^3$ 24 hr and 50 $\mu g/m^3$ annual average
- 1997 – Revised standards to $PM_{2.5}$ - 65 $\mu g/m^3$ 24 hr and 15 $\mu g/m^3$ annual average
- Over 1000 monitors nationwide to <u>gravimetrically</u> measure $PM_{2.5}$

PM and coal combustion

Coal combustion is generally viewed as a major source of $PM_{2.5}$ emissions into the atmosphere.*

Emission control technologies
Cyclones – for coarse PM (PM_{10}+)
ESP – for intermediate size PM (PM_{10}-/$PM_{2.5}$+)
Fabric Filters – for fine particles – clogging issues

*J.S. Lighty, J.M. Veranth, A.F. Sarofim, A. F., "Combustion aerosols: factors governing their size and composition and implications to human health", *J. Air Waster Manage. Assoc.* **50** (2000) 1565-1618.

Source Profiles of $PM_{2.5}$ (µg/g) Coal combustion PM is very different from rest of PM

	Coal Combustion	Vehicle Exhaust	Construction Dust	Fugitive Dust	Biomass Burning	Secondary Sulfates	Secondary Nitrates
Fluoranthene	1,186	2,828.4[a]	157.33	44.66	0.0	0.0	0.0
Pyrene	490	6,512.3[a]	93.20	29.58	0.0	0.0	0.0
Benz[a]anthracene	1,083	645.31	27.02	9.81	0.0	0.0	0.0
Chrysene	1,794	1,053.1	66.15	26.78	0.0	0.0	0.0
Benzo [k+b]fluoranthene	3,755	456.66	93.00	34.22	0.0	0.0	0.0
Benzo[e]pyrene	627	504.17	84.13	30.44	0.0	0.0	0.0
Benzo[a]pyrene	1,048	617.05	31.68	8.34	0.0	0.0	0.0
Perylene	365	85.03	3.38	2.36	0.0	0.0	0.0
Indeno [1,2,3-cd]pyrene	1,061	223.01	28.07	8.84	0.0	0.0	0.0
Benzo [ghi]perylene	836	232.61	30.45	9.40	0.0	0.0	0.0
Dibenzo [a,h]anthracene	240[a]	39.96	1.12	0.27	0.0	0.0	0.0
Organic carbon	24,800	390,000	0.0	186,800	484,000	0.0	0.0
Elemental carbon	10,700	365,000[a]	0.0	15,700	28,600	0.0	0.0
Aluminum	47,800[a]	2,160	42,600	73,100[a]	110	0.0	0.0
Calcium	4,400	3,373	300,000[a]	46,500	100	0.0	0.0
Potassium	11,000	2,111	16,100	12,100	16,700[a]	0.0	0.0
Nitrate	3,147	64,400	0.0	1,100	2,500	0.0	775,000[a]
Sulfate	263,600	28,000	0.0	11,000	2,500	727,000[a]	0.0
Ammonium	200	15,500	0.0	100	1,500	273,000	226,000

[a]Tracer.
Sources: Bergin et al., 2001; Hildemann et al., 1991; Tang, 2001

Need for separation

- Human mortality conclusions based on past instances
- Toxicological effects when source specific PM instilled in trachea of animals. Need to study inhalation effects
- Decouple harmful effects of other gaseous components from coal combustion e.g. CO, NO_x, and SO_x
- Different coals, combustion conditions, and emission control technologies have different PM

Uniqueness of coal combustion PM

- At high combustion temperatures all organic and volatile components are oxidized to gaseous phases
- Aluminosilicates are fluxed with alkali, alkaline earth, and iron to form molten phases
- Molten phases have spherical edges and move easily in and out of airways
- Combustion PM has distinctive chemistry and morphology – CCSEM
- Combustion PM is usually electrical insulator, and will retain static electric charge – electrostatic separation

CCSEM

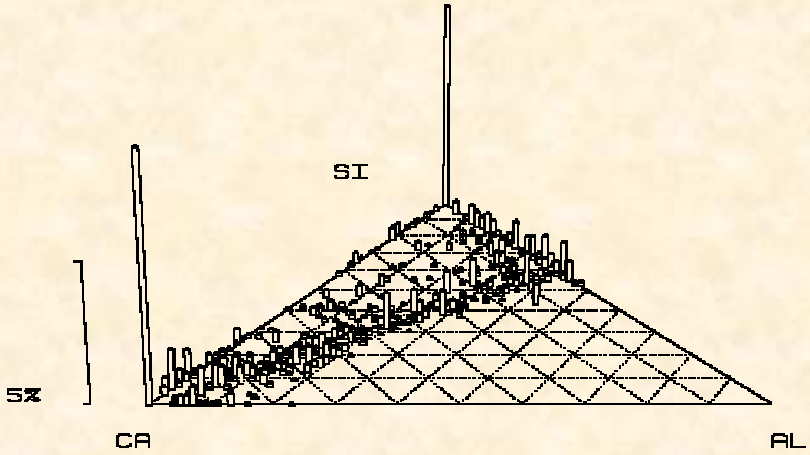
Computer Controlled Scanning Electron Microscopy

Thousands of individual particles analyzed for size, shape, and chemistry

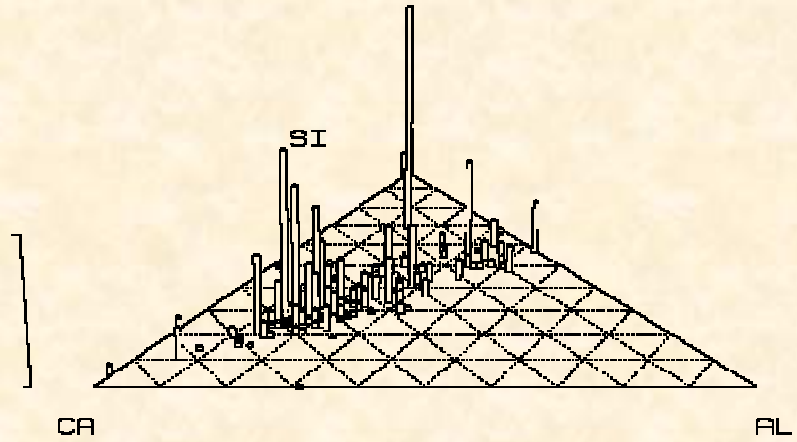
Ideally suited for defining source signature of PM from coal combustion

CCSEM - Coal combustion PM changes in chemistry due to size

MOUDI Impactor 1

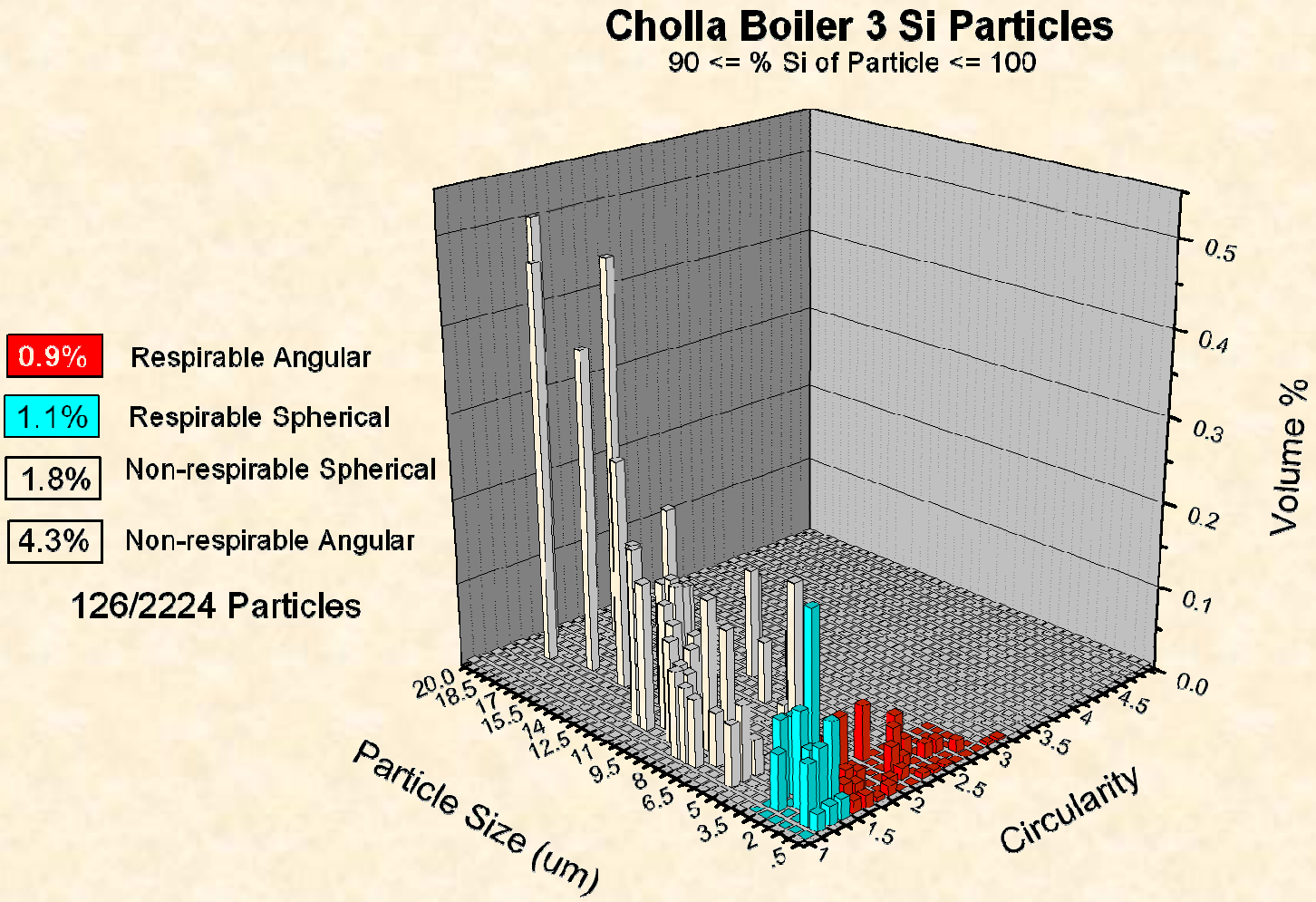


MOUDI Impactor 7



Ca-Al-Si volume frequency ternary diagrams of PM from combustion of Beulah coal. Note changes in the chemistry of different size PM collected at the same port.

CCSEM – quartz in coal ash



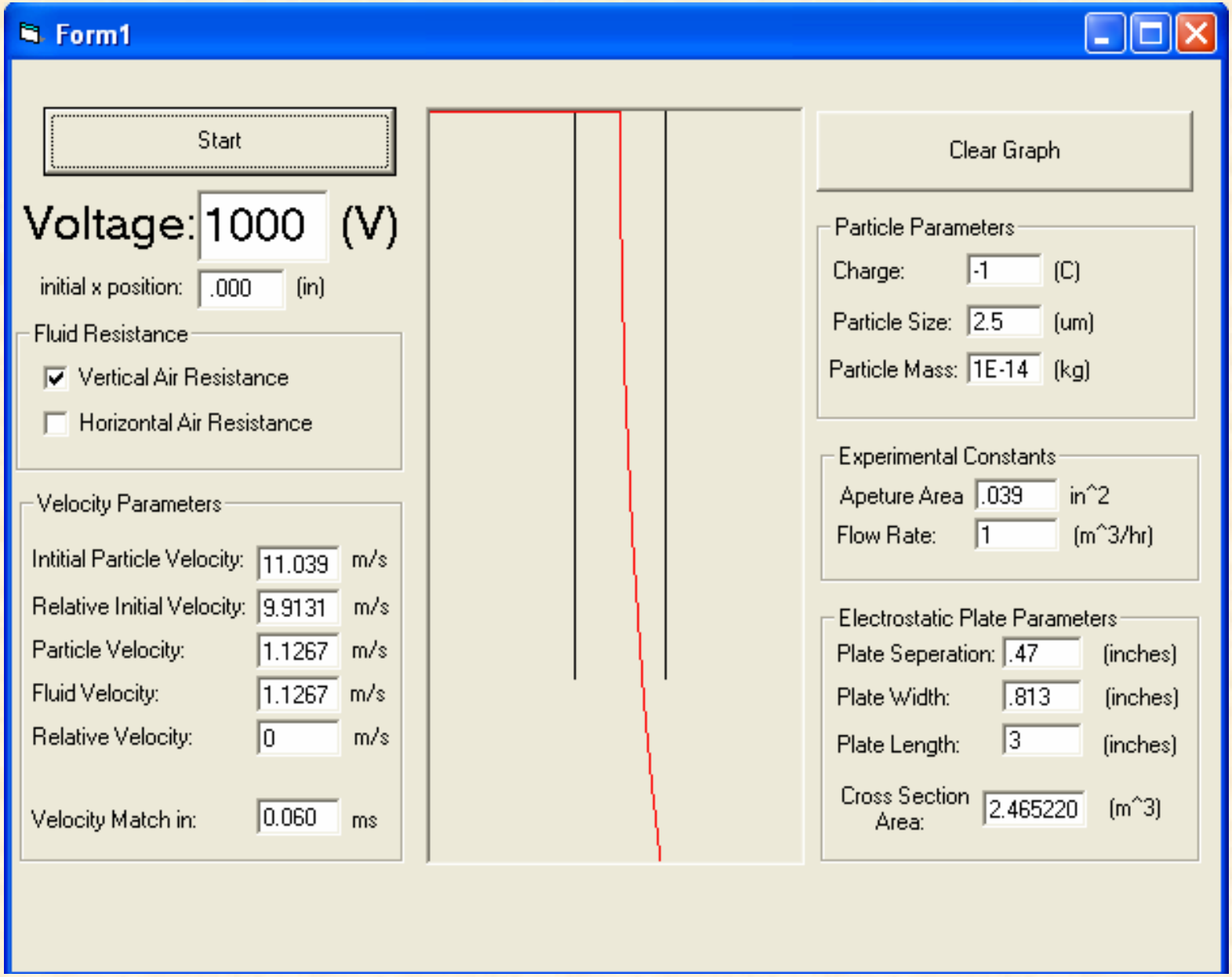
Objectives of this program

- Modify existing $PM_{2.5}$ sampler
- Design and build electrostatic deflector within the sampler
- Collect samples at different voltage conditions
- Examine samples with CCSEM for estimating separation efficiency
- Propose for phase II – Device to generate larger scale concentrated particulate stream for animal inhalation studies

Design criteria

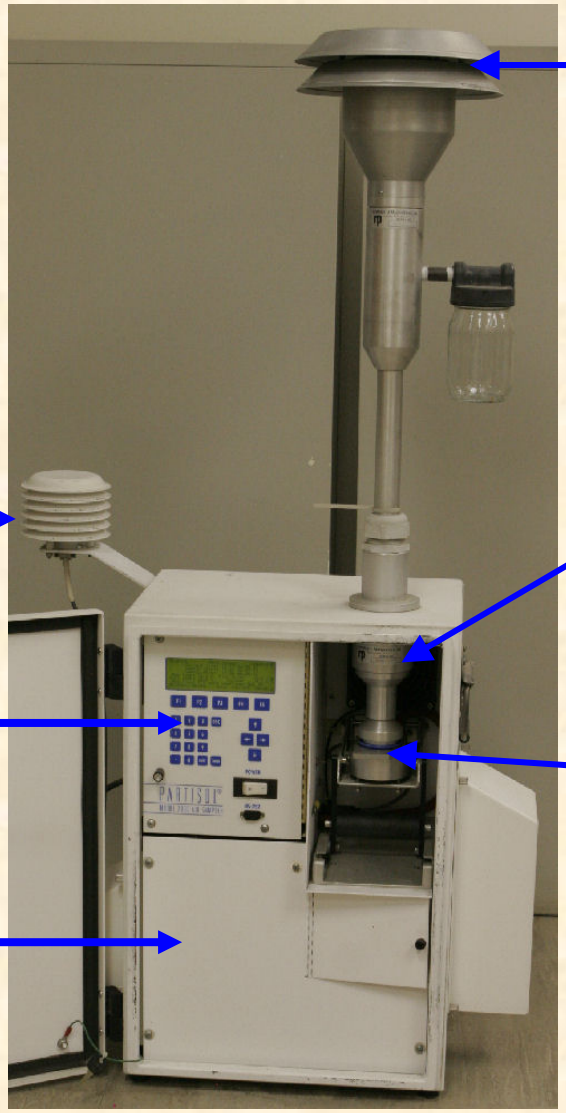
- Must fit within existing $PM_{2.5}$ sampler
- Must operate at 1 m^3/hr (16.7 l/min) flow rate
- Must be safe for high voltage

A visual basic program to determine the plate separation and voltages required


Form1
Start
Voltage: 1000 (V)
initial x position: .000 (in)
Fluid Resistance
Vertical Air Resistance
Horizontal Air Resistance
Velocity Parameters
Intitial Particle Velocity: 11.039 m/s
Relative Initial Velocity: 9.9131 m/s
Particle Velocity: 1.1267 m/s
Fluid Velocity: 1.1267 m/s
Relative Velocity: 0 m/s
Velocity Match in: 0.060 ms
Clear Graph
Particle Parameters
Charge: -1 (C)
Particle Size: 2.5 (um)
Particle Mass: 1E-14 (kg)
Experimental Constants
Apeture Area .039 in^2
Flow Rate: 1 (m^3/hr)
Electrostatic Plate Parameters
Plate Seperation: .47 (inches)
Plate Width: .813 (inches)
Plate Length: 3 (inches)
Cross Section Area: 2.465220 (m^3)

Instrumentation

Thermo Electron (previously Rupprecht & Patashnick) Model 2000 FRM sampler



Rain shroud and insect grill

Temp. & humidity sensor

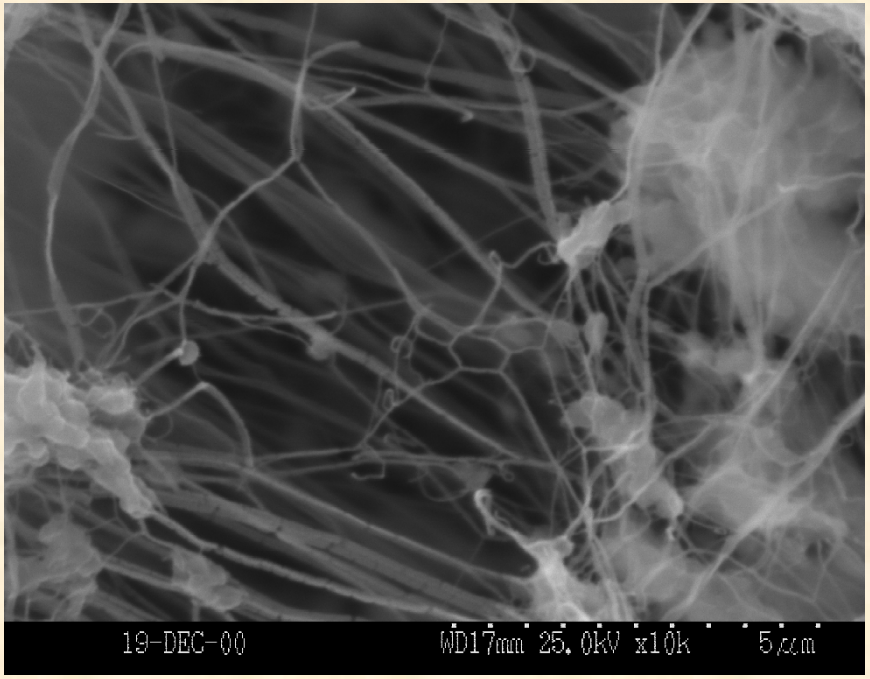
$PM_{2.5}$ WINS impactor

Electronics

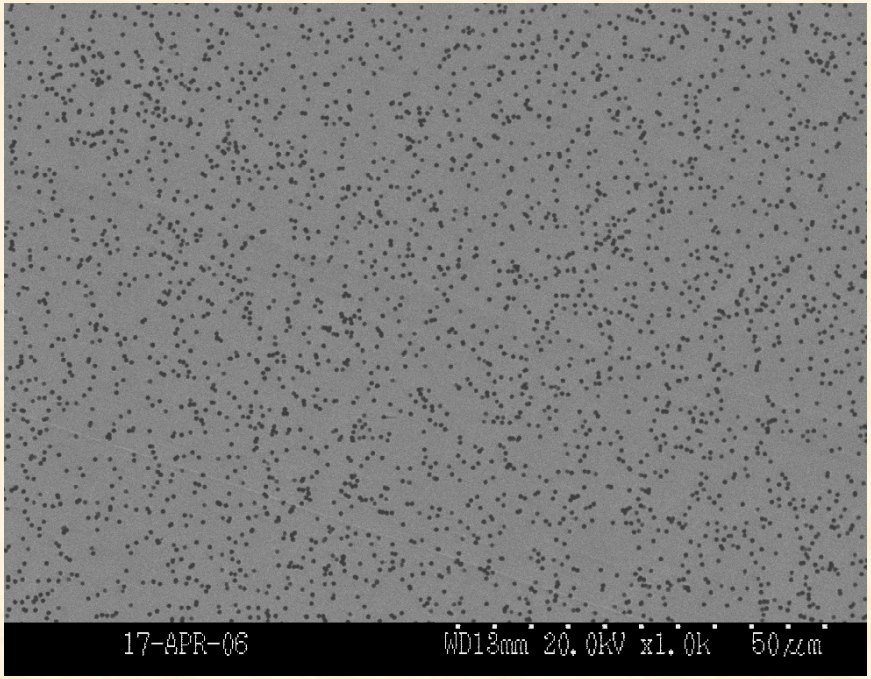
$PM_{2.5}$ collector filter cassette

Mechanical pump and air flow controller

Filter material selection

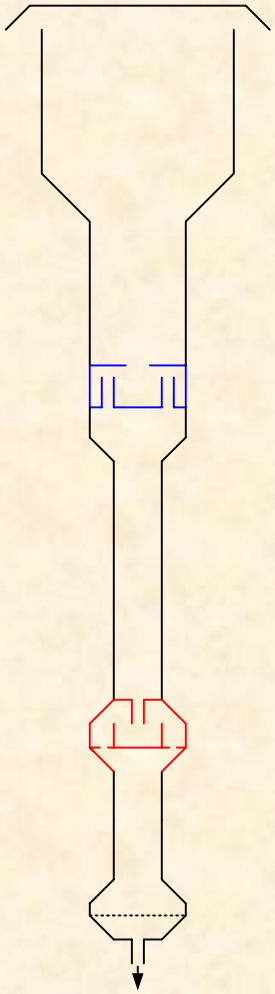


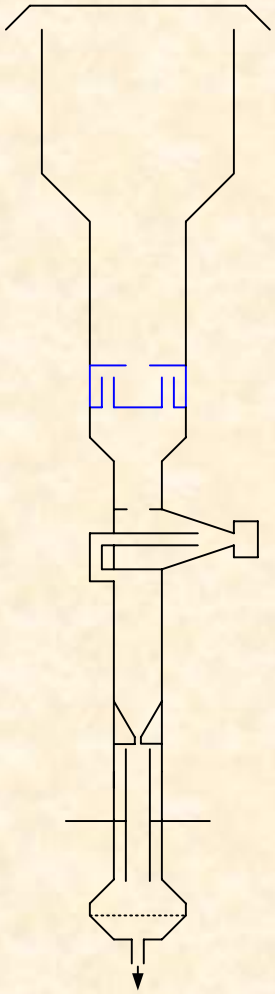
2μm PTFE Filter for gravimetric measurement



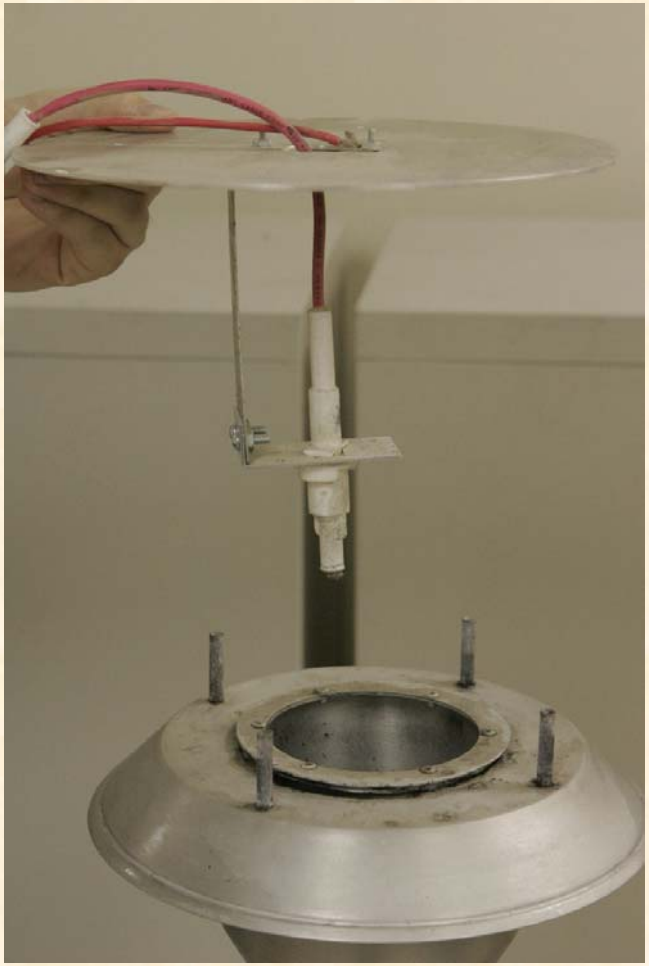
0.8μm polycarbonate filter for SEM measurement

Modifications to instrumentation

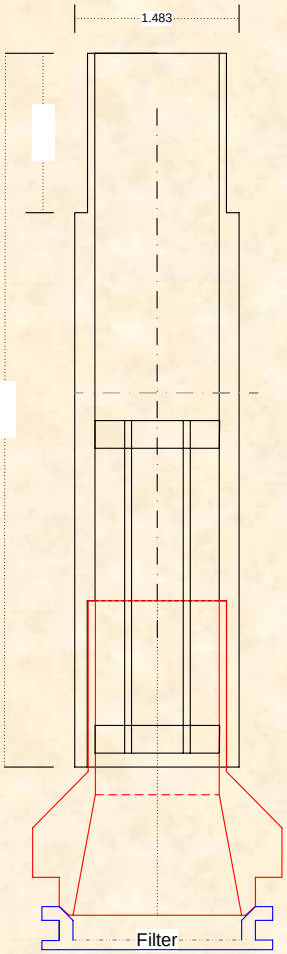


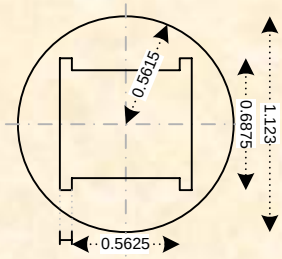


Modifications to instrumentation



Electrostatic deflector

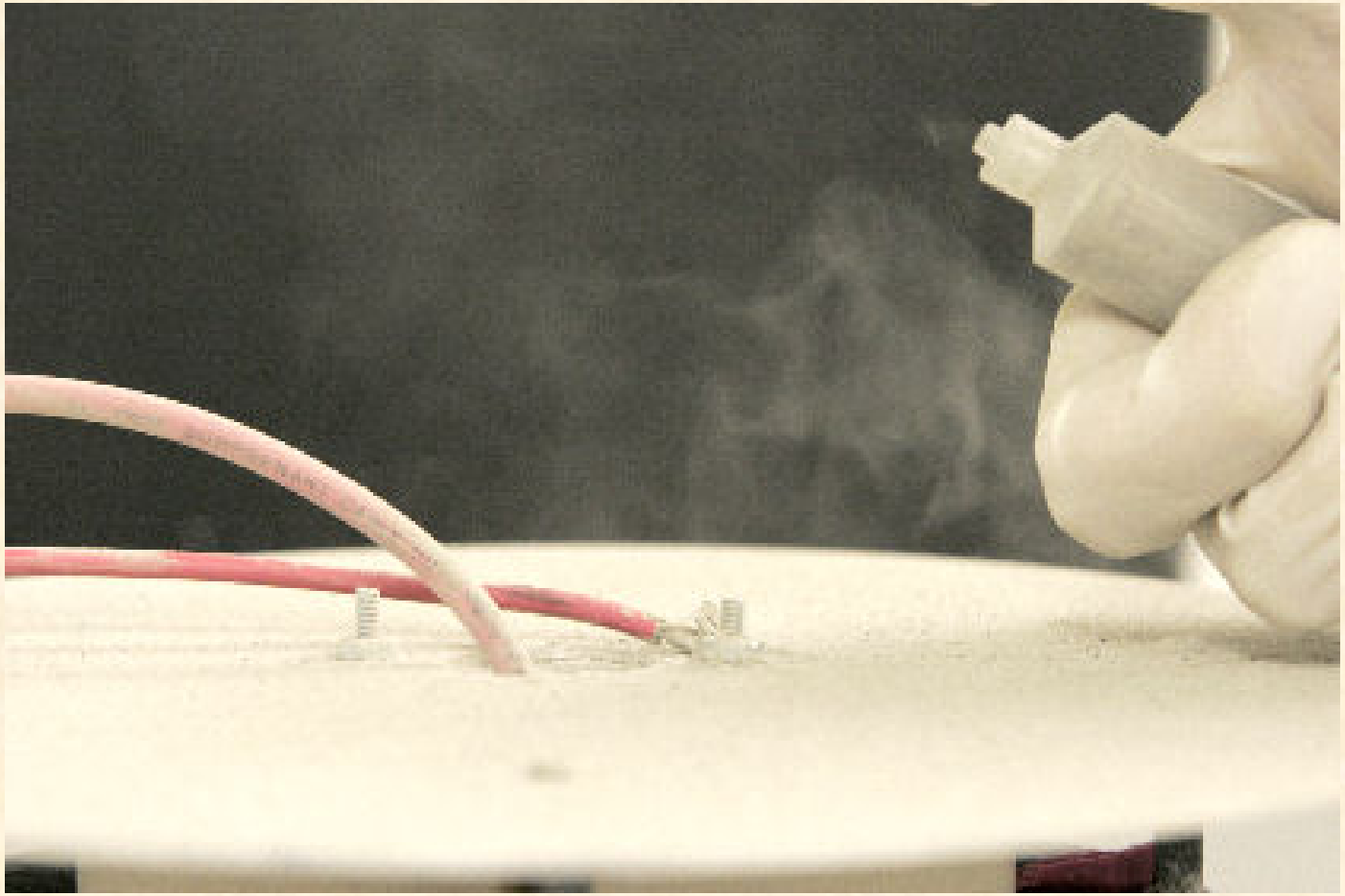




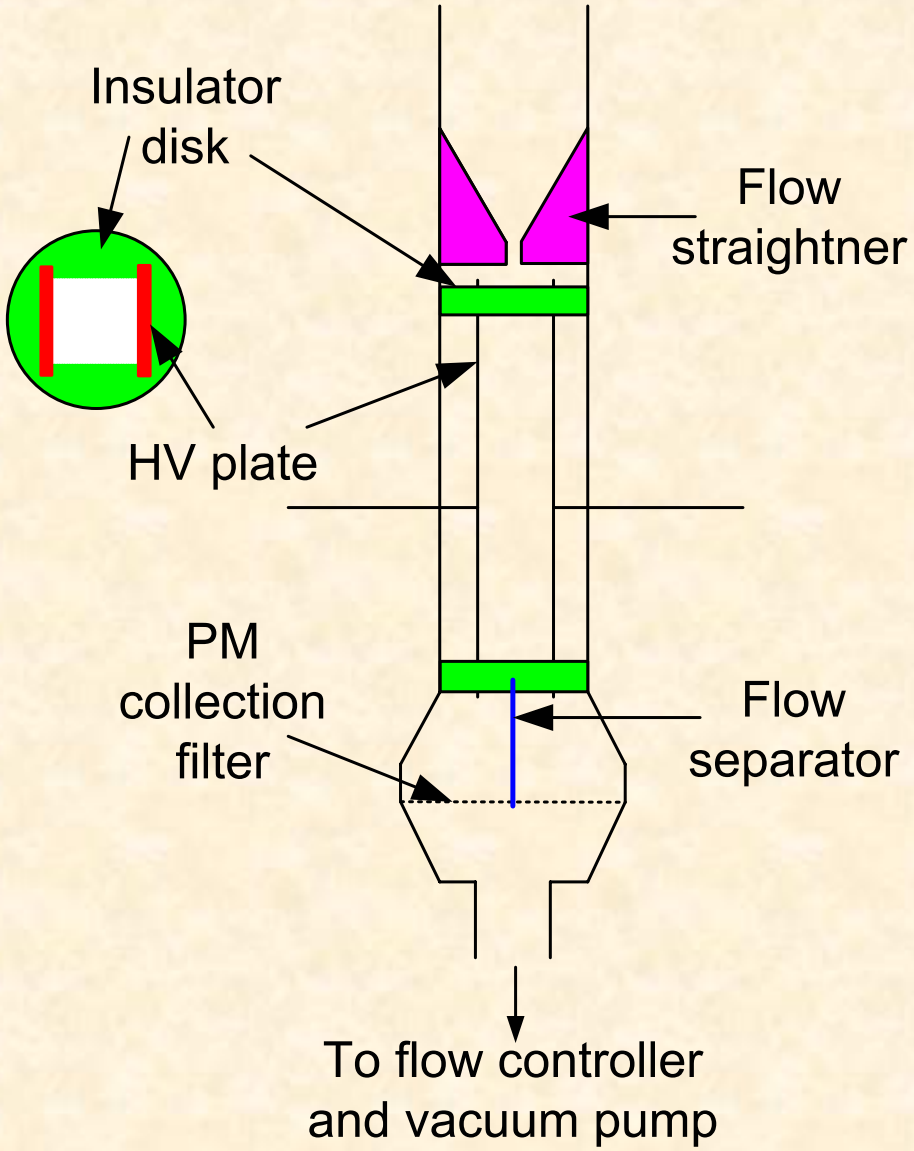
First results

- Not enough PM loading in the ambient air to collect meaningful sample within one hour of sampling
- Decided to spike ambient sample with flyash

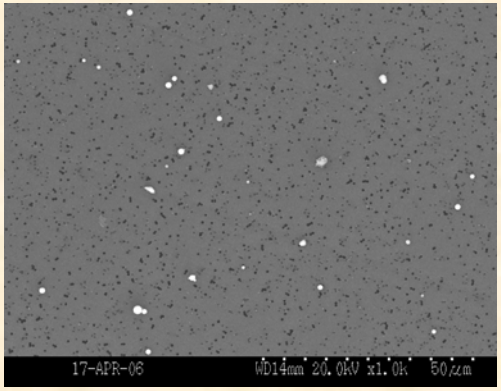
Sample spiking

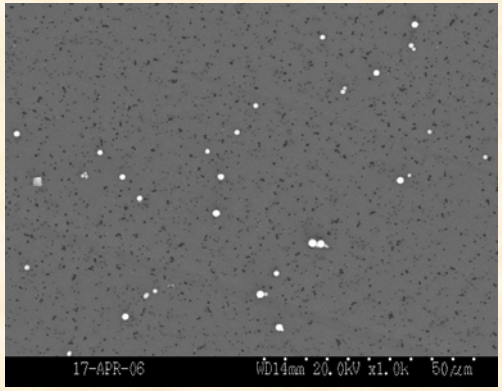


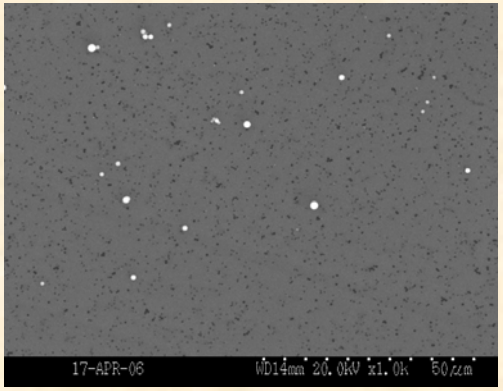
Further modifications

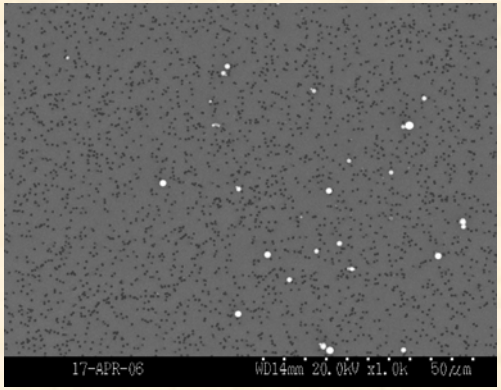


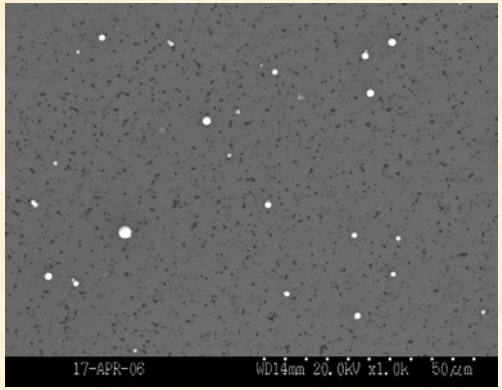
Close, but no cigar!

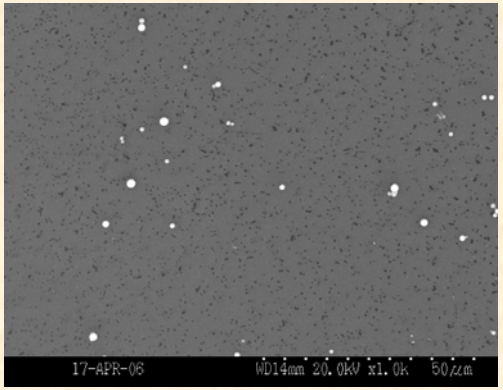




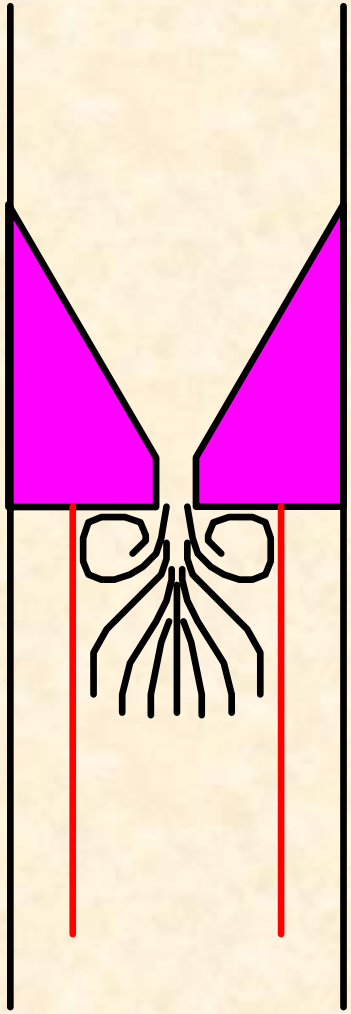








So what could be wrong?

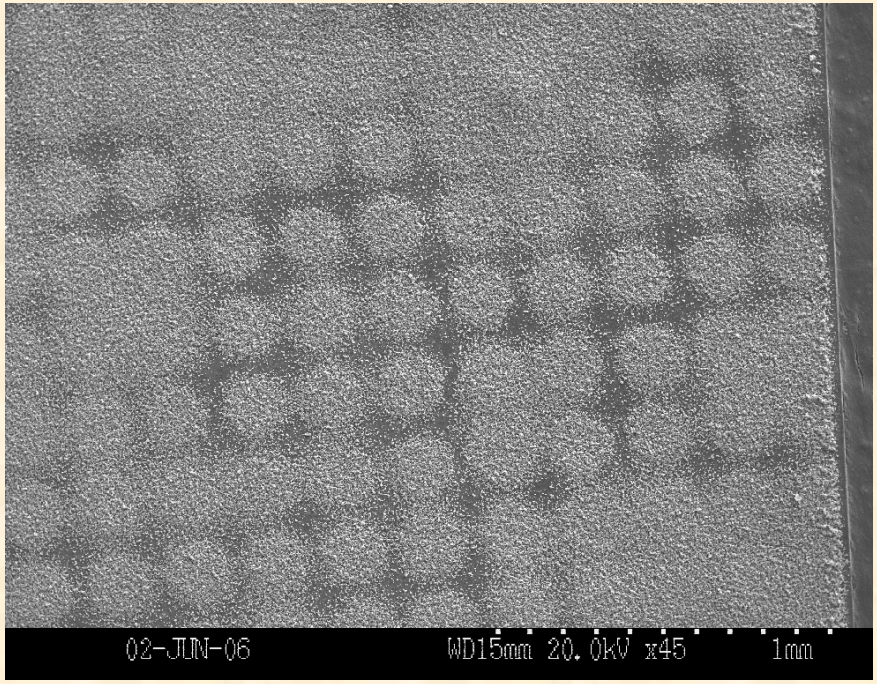


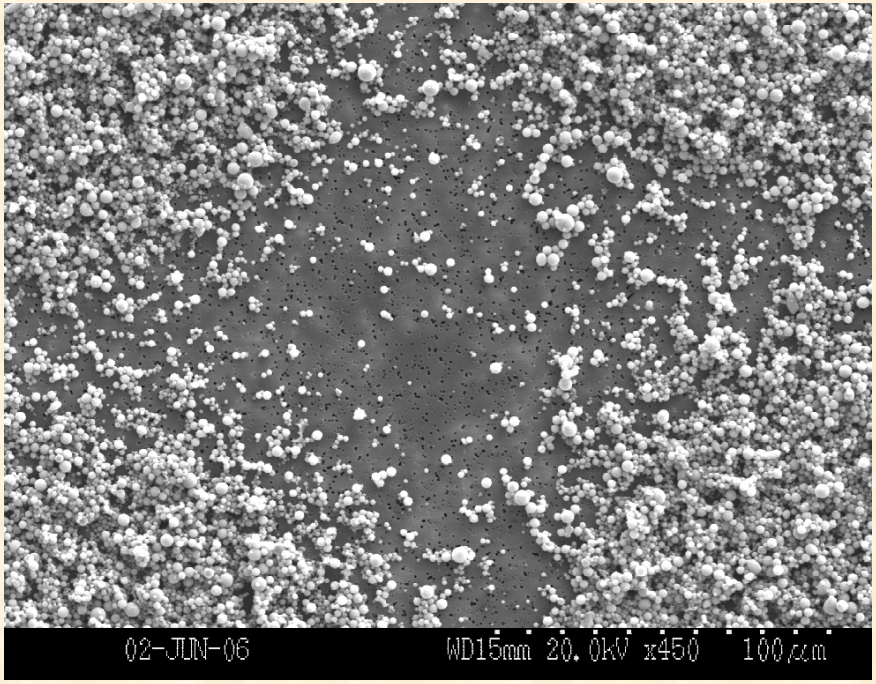
Turbulence sets in when linear air flow at 10m/sec in the flow straightner enters the electrostatic field and slows down to 1m/sec.

Fine PM follow the micro flow patterns of the turbulent/laminar flow

Electrostatic field force is not large enough to pull particles across flow lines within short distance

Micro flow paths

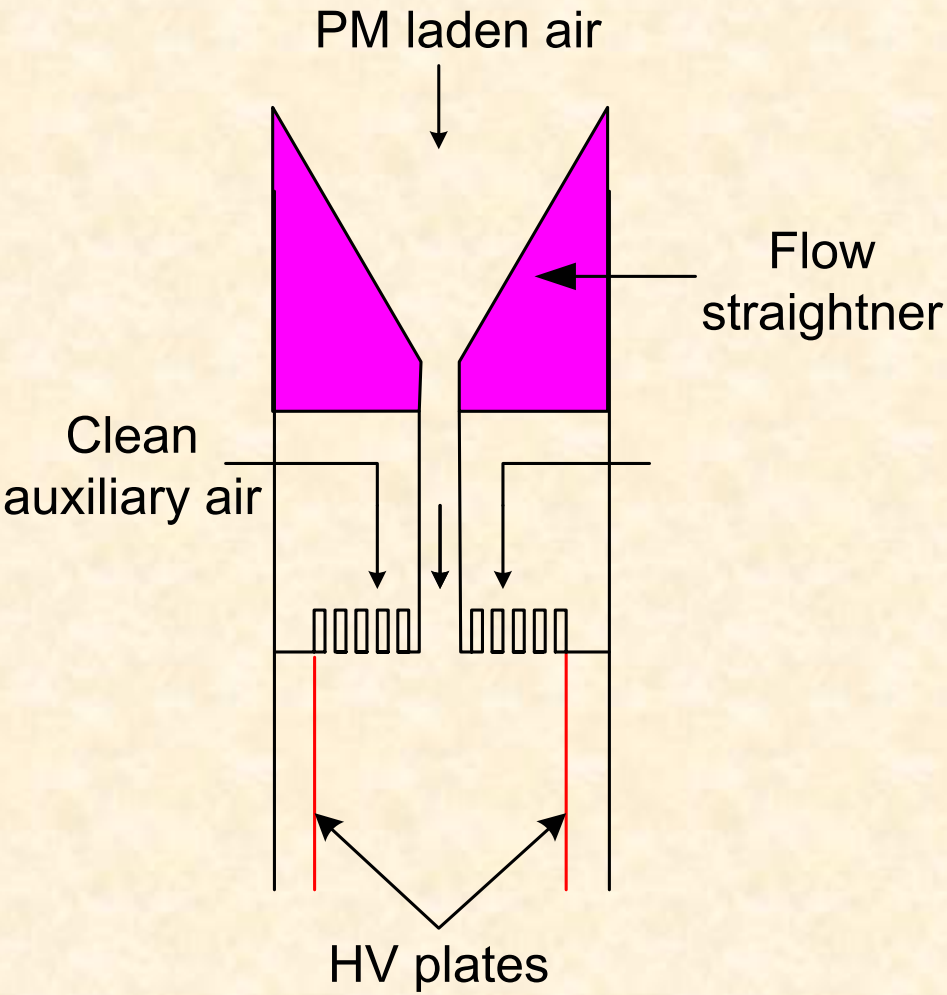




Conclusion

- Modified existing PM sampler to accommodate electrostatic deflector
- Successfully designed and built electrostatic deflector
- Incorporated additional modifications
- Tested electrostatic deflector with spiked sample
- Identified possible cause for unexpected observations

One possible solution



Supply auxiliary clean air parallel to and with the same linear velocity as PM laden air within electrostatic deflector region to maintain laminar flow and to avoid turbulence

Future Plans

- Electrostatic module appears to function well
- Geometric constraints of the existing sampler dictates complete redesign of airflow modules – instead of pull, use push strategy
- Design to direct concentrated stream towards exposure chamber
- Seek phase II funding

Acknowledgement

- Students: Nicholas Cprek, Mehul Suthar, Laal Baidu
- We thank Dr. John Stencel of Tribo Flow Separations (http://www.triboflow.com) for very helpful technical discussions
- This research was supported by the U.S. Department of Energy through University Coal Research (UCR) program under contract No. DE-FG26-05NT42543

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