

Tapered Element Oscillating Microbalance Technology

Applications for DPM Measurements



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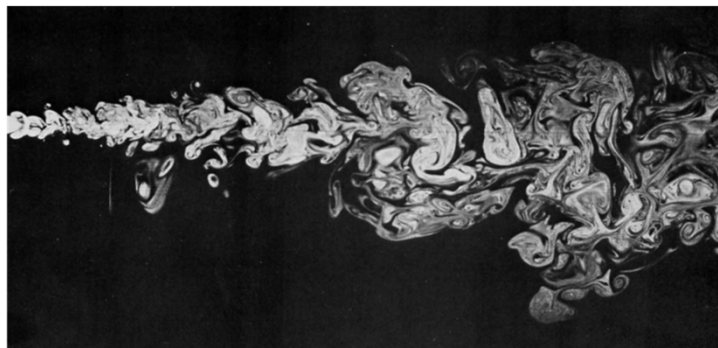
Jon Volkwein - NISOH



MDEC Oct 31, 2002

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What Are We Measuring?



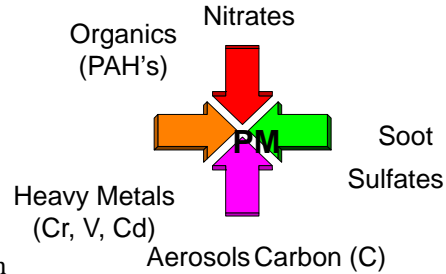
Mixing Plume of a Turbulent Jet – Non-linear Dilution



Courtesy of Nick Collings; University of Cambridge, UK

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Nature of Diesel Particles



- Can exist in either solid or liquid form, or a mixture of both
- Pre-trap PM (approximate ranges)
 - 20-90% non-volatile carbon and ash
 - 5-80% semi-volatile organic material
 - 1-30% hydrated sulfate (water considered volatile)
- Post-trap PM (high Pt, 15ppm S fuel)
 - 0-<3% carbon and ash
 - 1-95% organic material
 - 5-99% hydrated sulfate
 - **Water fraction can be over half the total PM Mass!**



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New Diesel Particulate Matter Regulations Filter Weigh Room Specifications

- More stringent temperature and dew point specifications
 - 22+-3C (+-1C at microbalance), 9.5+-1C dewpoint
- More stringent reference filter weight change: 10ug
- More stringent microbalance performance specifications
- Require balance operator grounding to balance
- Specified electrostatic neutralizer performance
- Allowed repeat weighing and statistical analysis
- Required buoyancy correction
- Recommended vibration, electrostatic, and draft isolation of microbalance
- Recommended Class 1000 clean room conditions



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TEOM Mass Transducer

- Tapered element oscillates at its natural frequency
- Particulate matter collects on filter continuously
- Frequency decreases with accumulation of mass
- *Direct* relationship between mass and frequency change



Tapered Element



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TEOM Monitor Mass Measurement Principle

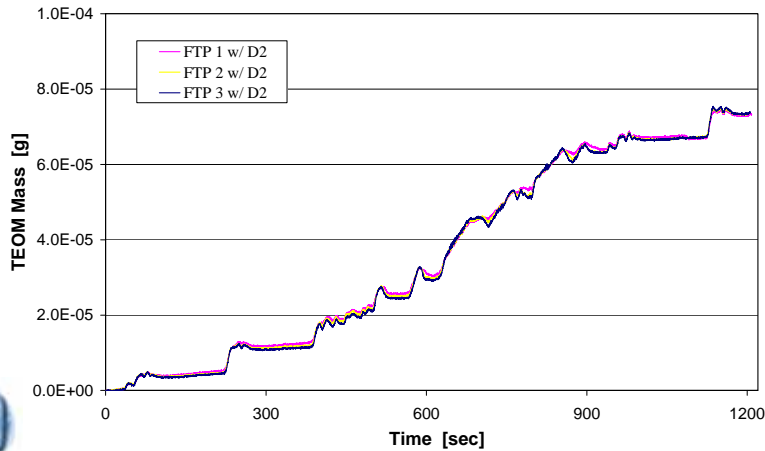
$$\Delta M(g) = K_o \left(\frac{1}{f_1^2} - \frac{1}{f_o^2} \right)$$

- The TEOM sensor is a mass detector
- Direct mass measurement independent of particle size, shape, composition, optical properties, density and surface area
- NIST-traceable mass calibration of the TEOM mass sensor—easily verified



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Triplicate FTP Runs, No. 2 Diesel TEOM Monitor



West Virginia University

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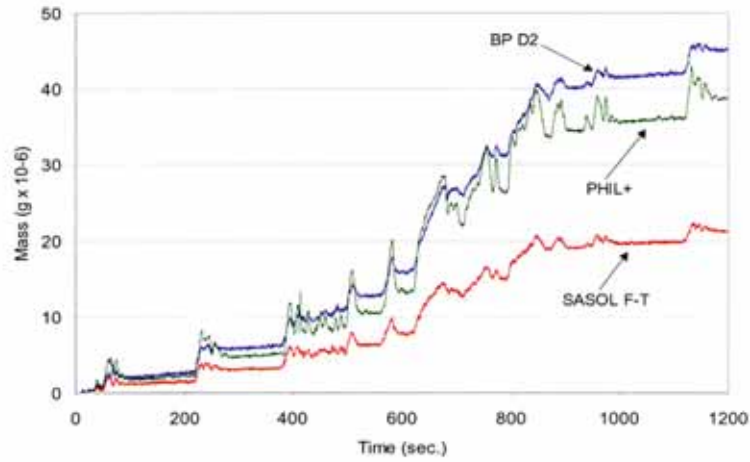
Fuel Specifications

	BP D2	Phillips Enhanced	SASOL F-T	Test Method
Density, kg/l @ 15C	0.8535	0.8247	0.7698	ASTM D-1298
Sulfur, by XRF %wt.	<.01	<.01	3.5 (ppm)	ASTM D-4294
Ash Content, %wt	0.002	0.003	<.001	ASTM D-482
Net Heat of Combustion, btu/lb	(18250)	18602	18890	ASTM D-240
Gross Heat of Combustion, btu/lb	(19361)	19850	20264	ASTM D-240
Cetane Index	(45.6)	53.9	75.8	ASTM D-4737
Cetane Number	(46)	51	74.6	ASTM D-613
Distillation, °C				ASTM D-86
IBP	(191)	181	164	
10%	(220)	204	183	
50%	(267)	256	244	
90%	(317)	312	332	
EP	(348)	349	352	
Hydrocarbon Type, Vol%				ASTM D-1319
Aromatics	23	30	0.7	
Olefins	2	3	1.2	
Saturates	75	67	98.1	



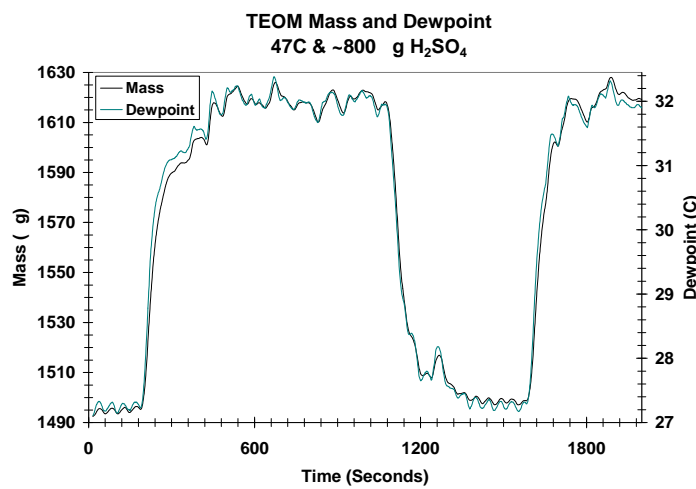
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TEOM Accumulation: FTP

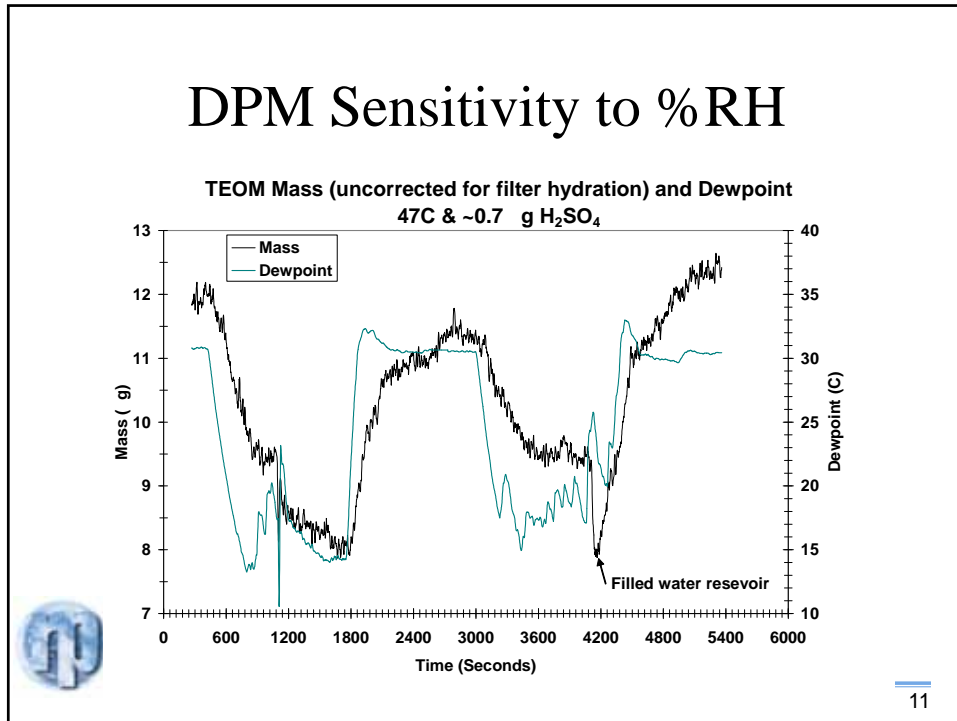


Source: Chris Atkinson, Nigel Clark et. al -West Virginia University - CRC On highway diesel Workshop paper March 2000

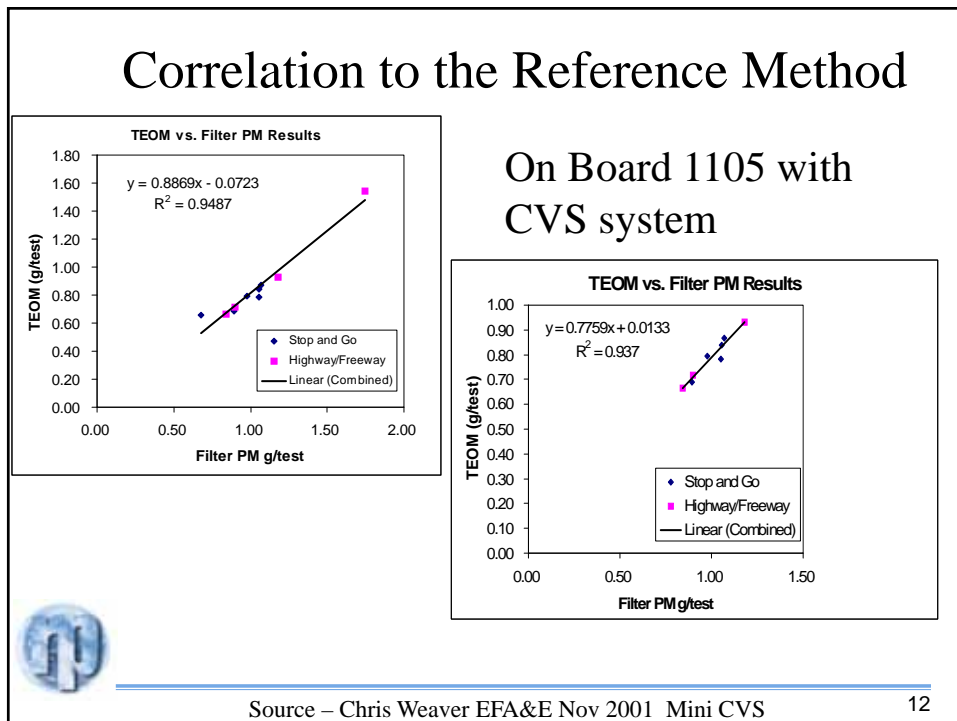
DPM Sensitivity to %RH



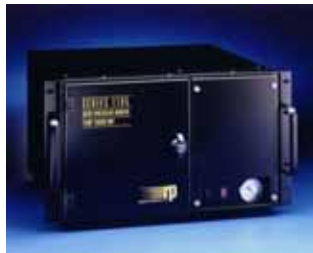
DPM Sensitivity to %RH



Correlation to the Reference Method



TEOM Miniaturization



TEOM Series 1105



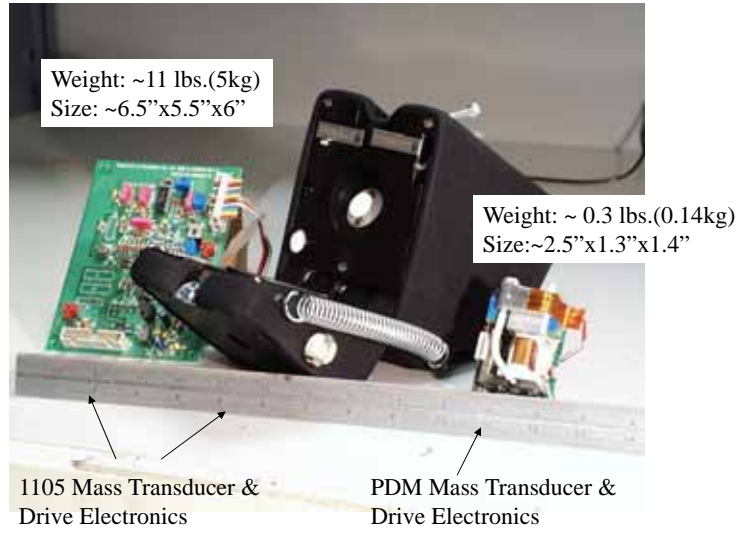
TEOM Series 3600 PDM



TEOM PDM Monitor

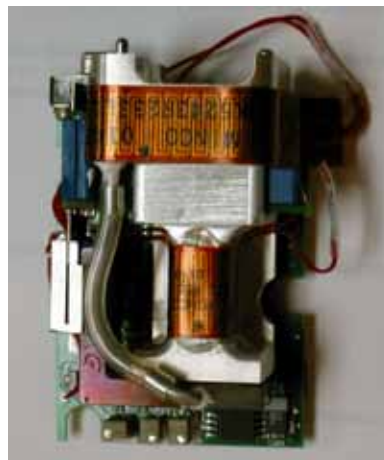


TEOM Miniaturization



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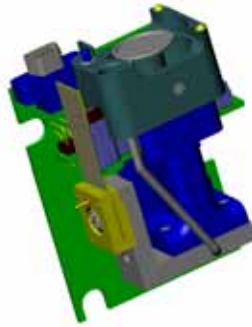
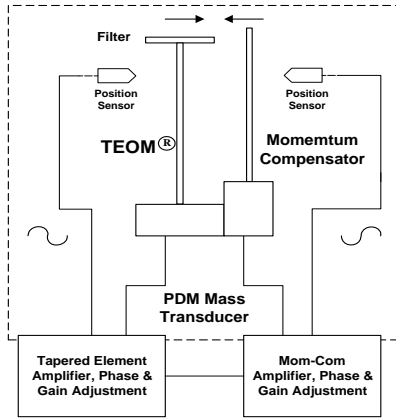
Miniaturized TEOM Sensor Detail



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Momentum Compensation System

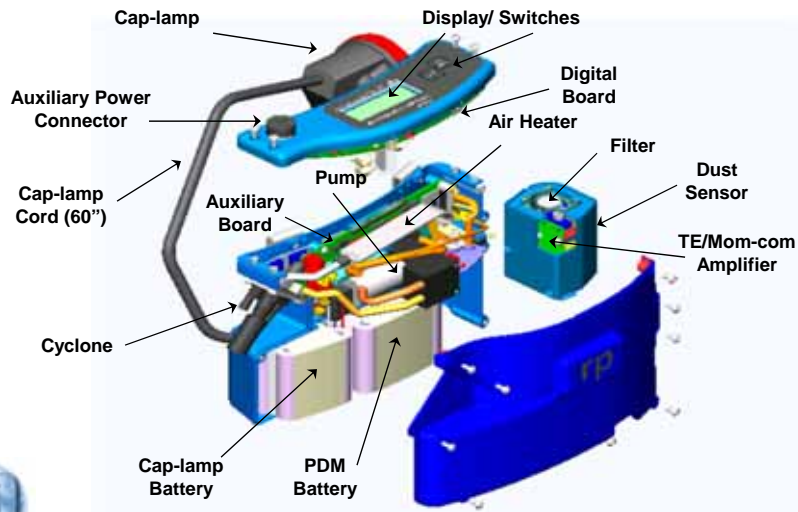
MOMCOM™ Technology



Schematic: Rupprecht & Patashnick Co. Inc.
TEOM-Based PDM Dust Sensor

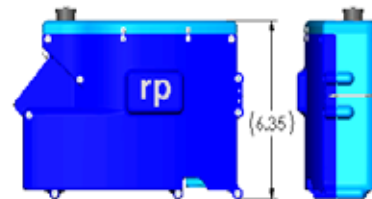
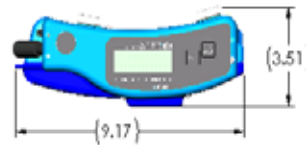


PDM: Exploded View



Physical Dimensions & Weight

- PDM -Weight Approx 6 lbs (2.3kg) with Cap lamp
- L: 23.4cm x W:8.9cm x H: 16.1cm
- Charger - : W: 8.4"x D: 5.8" x H:4.1"
Weight: 2.8 lb.(1.2kg)



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TEOM PDM Monitor

Major Features

- Real-Time Monitoring for Permissible Exposure Limits (PEL) of Coal Dust
- TEOM Technology for Filter-Based, Direct Mass Determination
- 12-Hour Power for Cap Lamp, Dust Monitor and Radio Control Unit – Target 14 hrs
- Designed for Intrinsic Safety approval by MSHA
- Data Integrity Through Hardware and Firmware Design
- Windows-Based Data Retrieval & Reporting



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PDM Sampling Modes

Compliance Mode

- Requires the use of WinPDM desktop PC software.
- WinPDM desktop PC software gives access to all configurable aspects of PDM including data logging parameters.
- Sampling parameters set and locked by WIN PDM before sample start time.
- Can only be aborted through the WinPDM desktop PC software.
- Contains information input by user through WinPDM desktop PC software to record sampling parameters on Dust Data Card.

Engineering Mode

- PDM logs data and controls temperatures most recently setup using WinPDM.
- Sampling duration can be set through the PDM membrane switches.
- PDM begins warming up for sample as soon as duration time selected
- May be aborted any time through the PDM membrane switches or the WinPDM desktop PC software.
- Cannot access Dust Data Card.



PDM Record of Tampering

Action	Evidence
Removing Dust Sensor:	Terminates shift and displays error message.
Blocking Inlet:	Both mass flow and pressure drop across filter record show action. Flow or filter error message displayed.
Sticking PDM in corner:	Ambient air temperature, pressure, and motion sensor records do not change over time.
Inserting filter in inlet:	Total mass collected and mass concentration too low.

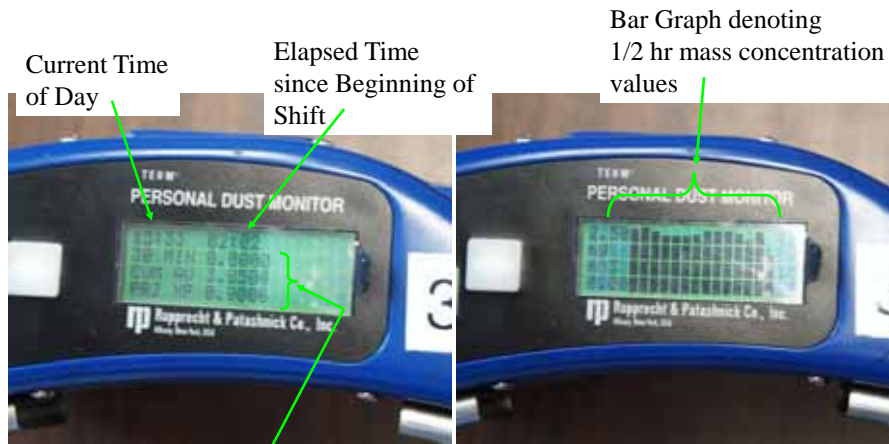


PDM Data Logging Capability

- Ambient air temp and pressure
- Pressure across filter
- Mass Flow Sensor readings
- Tilt Sensor information
- Raw Frequency
- Total Mass since sample start
- Current Mass Concentration
- Current Mass Rate
- Internal Instrument Parameters



PDM Display

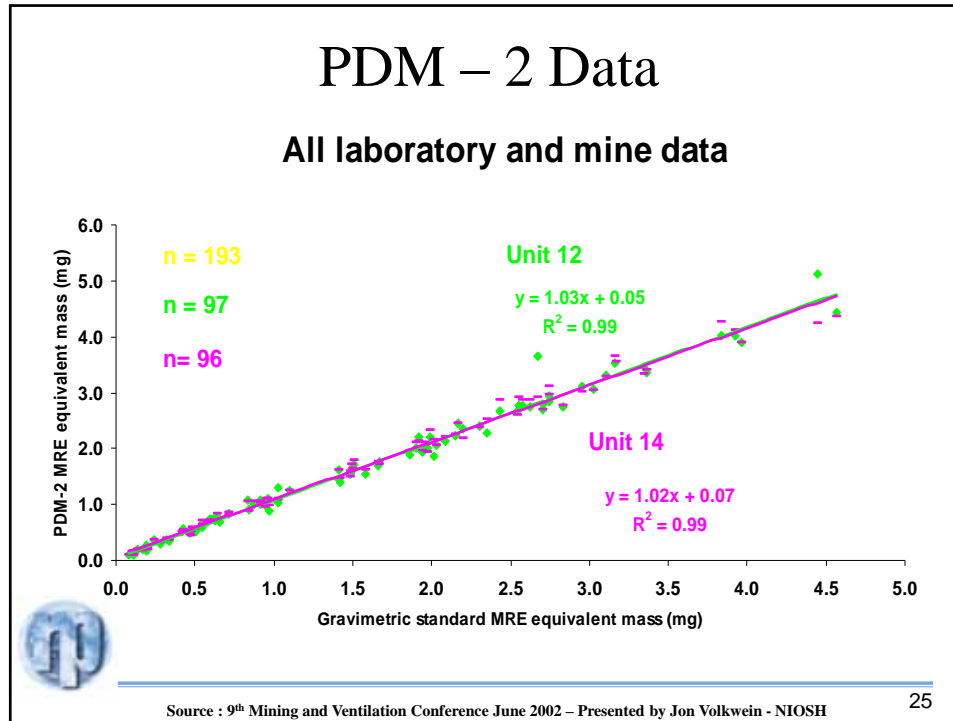


30 Min: Average mass concentration of the last 30 minutes

Cum Av: Cumulative mass concentration since beginning of shift

PRJ XP: Current exposure level based on entire shift duration





PDM-1 internally consistent

- Pre and post weigh PDM-1 filters on standard microbalance
- Electronic measurement of mass agrees with balance measurement of mass $\pm 4\%$ for 3 coal types measured



What effect on sampling history will moving inlet location from lapel to hardhat have?

- Within definition of breathing zone
- Lab and field study with beryllium show no meaningful difference (Cohen et al.)
- NIOSH laboratory shows no significant difference
- Preliminary UG data from 2 mines shows no difference



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Silica Determinations

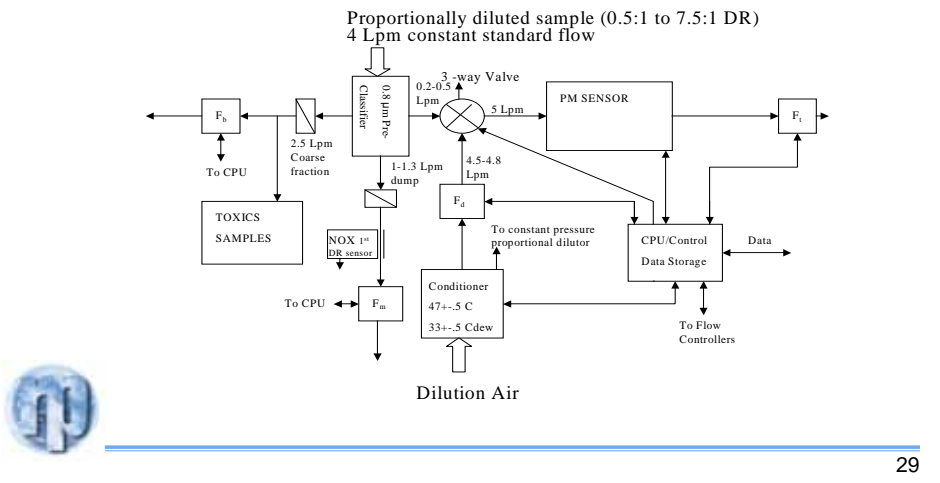
- Currently cannot be done because filter contains silica
- R&P has tapered element filter holders that are useable for P-7 silica determinations
- NIOSH is in process of evaluating new filter substrates – several promising candidates
- Need to build and verify new filters for efficiency, pressure capacity, and silica analysis
- More mass available than current samplers.
- Develop procedure for shipping and analysis.



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EPA On-Board Diesel PM Research and Development Project

Figure 1: Particle Mass Module



Summary

- TEOM method is the only Filter Based real-time direct PM mass measurement technology.
- TEOM based instruments have been proven in adverse environments with a high degree of Precision and Repeatability
- This project successfully developed a battery powered, miniature TEOM based, wearable dust monitoring system.
- The PDM TEOM monitor is designed to supply battery power for the cap lamp, remote mining controller and dust monitor in one package. (additional add on options are being investigated – methane, CO, radio battery power etc.)
- Development of a 0.8 cyclone for DPM exposure monitoring
- The current success with PDM TEOM technology gives USEPA the confidence to fund a project for development of an on-board, in-use DPM measurement system- Starting 2003

Acknowledgements

-  **MSHA** Mine Safety and Health Administration
Department of Labor 
- **NIOSH** *National Institute for Occupational Safety and Health*

