Environmental Monitoring with a Particle into Liquid Sampler (PILS)

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OUTLINE:
- Short course in aerosols
- Motivation for the measurement
- Introduction to the technology
- Power plant plume case study
- How could MEMS fit in?
Ambient Aerosols 101: Part 1

Particle Number Concentration
1/cm³

10⁷
10⁵
10³
10¹

Particle Diameter (nm)

1 10 100 1000 10000

Sulfuric Acid
Organic
Nitrate
Sea Salt
Mineral
Carbonaceous

Particle Number Concentration

Dry Dp Wet Dp

Elevated RH
Ambient Aerosols 101: Part 2
Motivation for the Measurement

Health Impacts

Climate Impacts

Air Quality Monitoring

Low Aerosol

High Aerosol

Process Monitoring

Emissions Characterization
Particle-Into-Liquid Sampler (PILS) Technology

- The PILS collects liquid samples that may be analyzed for multiple water soluble inorganic and organic species, and for total water soluble organic carbon.
Schematic of the PILS:
PILS Sampling Efficiency

100% Efficiency

- Sulfate
- Nitrate
- Chloride Species
- Ammonium
- Sodium
- Potassium
Customer Needs Satisfied:

- Automation
- Reliability
- Adaptability
- Cost Reduction
- Configurability
- Traceability
- Validation
Case Study of the PILS Applied to Chemical Processing in Power Plant Plumes

Acknowledgement to Seinfeld group at Caltech.
International Consortium for Atmospheric Research on Transport and Transformation
Case Study: Conesville Power Plant Plume Study

Wind speed ~ 6 - 12 m/s
Chemical Processing of Power Plant Plumes inside and outside of Clouds

Data courtesy Armin Sorooshian.

Literature reports slopes ranging from 0.0038-0.079

Overall for all Points ($y=0.028x$, $R^2=0.81$)

- Black dots: Clouds not Downwind of Power Plants
- Blue dots: Plume in Clouds
Chemical Processing of Power Plant Plumes inside and outside of Clouds

Wind

- SO$_4$ (µg/m$^3$)
- Oxalate (µg/m$^3$)
- Volume (µm$^3$/cm$^3$)

Plume Age (hr)
Future PILS developments: How could MEMS fit in?

MEMS based chemical sensor:
1. 5 ppb detection limit, x1000 dynamic range
2. Sensitivity to SO$_4$, NO$_3$, Na, Cl, K, NH$_4$, “Organics”
3. 30-100’s $\mu$l/min liquid flow rate range
4. Water and/or Methanol environment
5. 1 minute time resolution

MEMS liquid pump:
1. Process sample right at collection
2. Reduce microfluidics and sample handling
3. Integrate sensor close to liquid pump
Thanks for your time.

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**BMI PILS Flexible Sampling Features**

- **Multiple** sampling options:
  1) Autosampler to fill vials for later analysis,
  2) On-line IC, TOC, & other analyses

- Autosampler option allows multiple analytical techniques to be applied to a single liquid sample and reduces overall system size and sample acquisition time.

Photo of BMI Autosampler

BMI Autosampler with low-background vials. Septa in vial caps protect collected sample from contaminants.
BMI PILS Key Features

- Rapid PM1 or 2.5µm composition measurements
- Fully integrated system ready to use
- Ground-based or Airborne sampling capability
- Multiple analytical techniques possible
BMI PILS Key Features

- Syringe pumps for precise liquid sample flow control
PILS User Interface

Starting Configuration:
- Run Number: [Blank]
- Start time: 11:21:45 AM
- Minutes per Vial: 5.0
- Sample Flow Rate: 130 microliters/min
- Vial Fill Volume: 650 microliters
- Flushing: ON
- Flush Time: 30.0 minutes
- Start with Filter Vials: ON
- Num Sample Vials: 73

Current System Readings:
- Impactor Air Flow: 14.3 lpm
- System Pressure: 999 millibar
- Air Flow Humidity: 41 %RH
- Air Flow Temp: 18 deg C
- CO Pressure: 295 millibar
- Impactor diff Press: 6.5 millibar

Tip Temp: 99
Heater Temp: 225
Starting Carousel: 1
Starting Vial Num: 19
CAROUSEL POSITION: 0
CURRENT VIAL NUM: 19
Filter Vials Filled: 0
Transition Vials Filled: 0
Sample Vials Filled: 0
AIR FLOW VALVE: Filter

START PILS
TIME REMAINING: 00:00

User Message: Enter Settings and Push "Start PILS" button.
Current Function: Start Up
Hardware Status: 

Manual Control:
- Take Filter Vials Now: 3
- End With Filter Vials: 3
### BMI PILS Configuration Utility

#### File Paths
- **Path to Log Files:** `% c:\PILS\Logs`
- **Path to Data Files:** `% c:\PILS\Data`

#### System Flow Settings
- **Sample Syringe Size:** 100 microlitres
- **Sample Flow Rate:** 130 microlitres/minute
- **Vial Fill Time:** 5.0 minutes
- **Vial Fill Volume:** 650 microlitres
- **Sample Tubing Length:** 57 inches (add 6" for needle mtr assy)
- **Washflow Syringe Size:** 250 microlitres
- **Washflow Flow Rate:** 150 microlitres/minute
- **Mixing Factor:** 1.3
- **Steam Feed Rate:** 1.5 milliliters/minute

#### Sensor Calibration Values
- **Impactor dPress Slope:** 13.896 millibar/volt
- **Impactor dPress Offset:** -13.504 millibar
- **CO Press Slope:** 205.666 millibar/volt
- **CO Press Offset:** -225.574 millibar
- **System Press Slope:** 206.883 millibar/volt
- **System Press Offset:** -223.077 millibar
- **Impactor Flow Slope:** 20.918 lpm/volts
- **Impactor Flow Offset:** -15.688 lpm
- **Impactor Cal Press:** 990 millibar
- **Air Flow Temp Slope:** 22.05 deg C / Volt
- **Air Flow Temp Offset:** -47 deg C
- **Air Flow Humidity Slope:** 20 %RH / Volt
- **Air Flow Humidity Offset:** 0 %RH
- **Peri Pump Cal Slope:** -0.20619
- **Peri Pump Cal Offset:** 0.8295

#### Automatic Control Settings
- **Heater Target:** 215 deg C
- **Heater Cntrl Pt:** 57 (35-55)

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**Discard Changes** | **OK**
**Save Settings** | **OK**
BMI PILS Remote Control Feature

- Acquisition times of sample may be controlled by a remote host computer through optional software
Schematic of PILS Operation
Intercomparison of PILS & SEMS Measured Ammonium Sulfate Mass
BMI PILS Technical Details

- 12-15 lpm air sample flow rate; 1 mm D50 impactor cutoff
- Denuders installed upstream to remove potentially interfering inorganic and organic vapors
- 0.02-1.0 ml/min liquid sample collection flow rate
- 30 second to 12 hour sample time provides 0.1-20 ml of collected sample in either poly (1.2 ml) or glass (2, 10 & 20 ml) vials
- Power: 230 watts @ 115 VAC (excluding air pump)
- Size: 19” rack-mountable frame 19” deep, 26” high.
- Weight: 115 lb