ADVANCED AEROSOL SAMPLING TECHNOLOGIES FOR POINT BIODETECTION

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# Advanced Aerosol Sampling Technologies For Point Biodetection

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Trigger vs. Collector

- Trigger
- Collector
- Confirming Sample
- Identifier

Initiate → Collector
Fluid → Identifier
Air inlet

Bio Detector Components
Example Biodetection Systems
Trigger Inlets & Collector Inlets

BIDS

INLET
Large particle remover
Multi-stage CONCENTRATOR
COLLECTOR

JBDDS
Typical Aerosol Sampling System

Particle losses throughout a sampling train

Relative # of target particles in air

Aspiration Efficiency $\eta$

Transmission Efficiency

Collector Efficiency

• Inlet
• Fractionator (large particle impactor)
• Ducts
• Concentrator
• Collector

$\eta_0 = \prod \eta_{components}$

Collector component concentrates target particles into detection medium
Aerosol Particle Behavior

- Settling
- Impaction

TAKE-HOME MESSAGE:

Aerosols are NOT gases.

Their inertia gives us a handle on them.
Their inertia can confound our efforts to transport them.
Material is sparsely distributed in space.
Particle Settling in Still Air

Time to settle 5 feet by unit density spheres

<table>
<thead>
<tr>
<th>Diameter (µm)</th>
<th>Time to Settle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>41 hours</td>
</tr>
<tr>
<td>1</td>
<td>12 hours</td>
</tr>
<tr>
<td>3</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>10</td>
<td>8.2 minutes</td>
</tr>
<tr>
<td>100</td>
<td>5.8 seconds</td>
</tr>
</tbody>
</table>

Aerodynamic diameter: diameter of unit density sphere that settles at the same velocity as particle in question

Sampling trains are usually vertical and avoid bends, horizontal.
- requires size dependent characterization over 1-10 micron.
Particle Settling in Still Air

Time to settle 5 feet by unit density spheres

- 0.5 µm: 41 hours
- 1 µm: 12 hours
- 3 µm: 1.5 hours
- 10 µm: 8.2 minutes
- 100 µm: 5.8 seconds

~ 100-fold difference
Both Large and Small Sizes are Difficult to Sample with High Efficiency

Too little inertia – impactor concentrators and collectors require high acceleration

Too much inertia – difficult to aspirate and transmit through tubing to collector without wall losses

Typical sampler efficiency data
Aerosol Sampler
Technology Challenges

**Goals**

- High efficiency inlets for 1-10 micron particles and wind speeds (stationary outdoors up to 15-20 mph, HVAC up to 25 mph, vehicles/ships maybe 60 mph?)
- High efficiency, low power aerosol concentrator for 1-10 micron particles
- Low temperature (range of US cities) aerosol collector for wet samples
- Dry aerosol collectors
- Triggered vs. Long term “sentinel” wet and dry aerosol collectors
- Viability-preserving aerosol collectors

**Description**

Provide advanced collectors and inlets
- smaller
- lighter
- less power
- inexpensive
- sub-freezing
- higher concentration liquid sample
Aerosol Sampler Performance Issues

• Detection Sensitivity (collected amount and concentration)
  – Air flow rate (sample size vs. time)
  – Collection Efficiency (particle size dependent – 1-10 micron)
  – Reject unwanted sizes, e.g., pollens
    • background suppression, dust
  – Concentration factor (into liquid or air)

• Utility
  – Rise time, Clear down time
  – Low & high temperature
    • wet collectors
    • dimensional stability, air viscosity
  – Clean up/Decon

• Logistics
  – Power consumption (incl. low temps)
  – Size & Weight (portability)
  – Liquid requirement (recirculating?)
  – Rugged, reliable, maintainable (lab devices unsuitable in field)
Bio Detection Systems

Aerosol Sampling Subsystem
- Inlet
- Fractionator
- Aerosol Concentrator
- Wet Collector
- Dry Collector

Biological Analysis Subsystem
- Optical Trigger
- Immunoassay
- PCR
- Sample Prep
- Mass Spec
- Py-GC-IMS/MS
- MALDI MS

SAMPLE
Vol Conc
Size Amount
Bio Detection Systems

Aerosol Sampling Subsystem
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Biological Analysis Subsystems
- Optical Trigger
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Matrix mixing
## Advanced Aerosol Sampling Technologies

<table>
<thead>
<tr>
<th>Conventional Inertial</th>
<th>Next Generation Inertial</th>
<th>Non-inertial Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved large particle rejection</td>
<td>Shrouded probes (for wind, moving platforms, or HVAC ducts)</td>
<td>Low power inertial concentrators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low power, low temp wet collector</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrostatic concentrator/collector</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impeller collectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micro array dry collector</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrosol Concentrator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acoustic concentrator</td>
</tr>
</tbody>
</table>

### Power example
- Conventional Inertial: ~500W
- Next Generation Inertial: ~150W
- Non-inertial Technologies: ≤100W
- Impeller collectors: 40 - 20W
- Acoustic concentrator: ≤10W

**FY04 Technology**

Future Capabilities
EXAMPLES OF ADVANCED SAMPLING TECHNOLOGIES

CAVEAT: The following examples are given to illustrate each of the advanced aerosol sampling technologies currently being explored. This is not intended to be a complete catalog of all the applications of these technologies under development.
CONVENTIONAL INLET
heavy dust penetrates the fractionator
CONVENTIONAL INLET WITH OILED PAD
oiled pad improves fractionator for retaining large particles such as dust
Inlet Efficiency as Function of Wind Speed
Various Particle Sizes for an ~100 LPM Omnidirectional Inlet
SHROUDED PROBE INLET
Large Shrouded Probe Inlet

1,000 lpm Class Shrouded Probe

Comparison of Shrouded Probe & Conventional Omnidirectional Collector Inlet Performance
8 micron particles

Inlet Efficiency (%) vs Wind Speed (mph)
Shrouded Probe Inlet

- Shrouded probe inlet is superior at high wind conditions when pointing into wind, for example, in HVAC ducts.
- Yaw angle performance is good at low wind conditions. Sampling when wind is coming from side is not degraded considerably when compared with a simple omnidirectional inlet.
- Application: Shrouded Probe might replace omnidirectional inlets in outdoor situations and enhance windy and moving-platform performance without seriously degrading performance. (Full range of wind speeds and particles sizes remains to be studied.)

![Graph showing Yaw Angle Performance of 100 l/m Shrouded Probe](image-url)
New Concentrators Under Testing

mini slits process small particles with low pressure drop

Test Bed for mini-slit design

High flow (3,000+ lpm)
Virtual Impactor Concentrator using a large horizontal array of mini-slits
New Aerosol Collector using mini-jets to capture small particles with low pressure drop

Energy Efficient
Low Temperature Wet Collector
Electrostatic Collection …versatile technology capable of interfacing to many detection systems…

AEROSOL

Corona-charging

Electrostatic Focusing & Deposition

Liquid

Wetted Column Collector

Self-cleaning Hydrophobic Membrane

Assay or Antibody Detection System

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Compact Electrostatic Aerosol Concentrator

...capabilities: compact, low power, high flow rate...

- Direct aerosol concentration without energy consumptive inertial separation process upstream
  - Pressure drop orders of magnitude lower than inertial separation collector
  - Multi-unit samples >200 LPM with 1 watt fan
- Integrated high efficiency corona charger & collector for minimal size
- Particles deposited into small volume of liquid (< 1 ml)
- Low cost – low weight injection molded plastic construction

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Electrostatic Radial Collector Performance

...original configuration vs. high density array data...

Electrostatic deposition of 2.3 µ beads onto a 0.125 in. diameter dry post from 0.75 in. diameter duct

High Density Corona Array
Collection Efficiency
>85% @ 30 lpm

Electrostatics Off

Original Configuration Corona Array
Collection Efficiency
>50% @ 30 lpm

Electrostatics On

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IMPELLER EXAMPLE

ROTATING ARM COLLECTOR

BioCapture Air Sampler
Micropillar Array Dry Collector

A low pressure drop, high flow filter with collection efficiency of a good aerosol collector (80-90%).
Particle Trajectories Through three rows of offset rectangular micropillars

Figure 1. (a) Pressure Drop and droplet trajectories (b) Velocity Profile corresponding to an inlet velocity of 5 m/s and for particles of 1 μm size with a 5V voltage potential.
Micropillar Results

Aerosol Capture on **Uncoated** Micropillars at 1” Water Pressure Drop: 1-Micron PSL

Aerosol Capture on **Coated** Micropillars at 1” Water Pressure Drop: 1-Micron PSL
Example Hydrosol Concentrator

Two-Level Designs using dielectrophoresis (DEP)

UNIFORM FIELD DESIGN:
1) Electrochromatography: Dispersion Minimization
2) Particle Filtration: Bandwidth Minimization
Simulation of particles sliding along ridge and out tube (forked splitter)

No DEP

With DEP

With DEP (Animation)
Forked Splitter Results
(*Bacillus subtilis*)

Deep Inlet

Shallow Ridge

Deep Outlets:

1

2

3

5 V

250 V

500 V
ACOUSTIC CONCENTRATION IN AEROSOL FLOW

Particle Trajectories    Video of Exit Flow
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