Characterization and Improvement of the Versatile Aerosol Concentration Enrichment System (VACES)

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What does VACES do?

VACES concentrates particles over a wide size range for use in toxicology studies.

How?

-- Impact particles to remove large ones.
-- Warm, humidify, saturate incoming ambient air.
-- Cool air to supersaturate and grow the particles.
-- Concentrate the particles in a virtual impactor.
-- Dry the air to reduce the particle size.
What does VACES do?

- Major Flow: 100 LPM
- Virtual Impactor
- Minor Flow: ~10 LPM
- Diffusion Dryer
- Exposure

Aerosol Inlet

- Cooler at –8°C
- Warm Water Bath
- T = 28 - 32°C
- RH ~ 100%

0-110VAC Heater
Why Perform this Study?

VACES used by many toxicologists for Concentrated Ambient Particle studies (CAPs)

Reports of Temporal Variability in Enhancement Factor
  -- Due to change in ambient conditions?
  -- Due to exhaustion of silica drier gel?
  -- Due to lowering of water bath level due to evaporation?
  -- Due to icing of the cooler?
  -- Due to water build-up in the virtual impactor
Why Perform this Study?

VACES used by many toxicologists for CAPs

Concerns about Concentrating the High Volatility, High Solubility Gases

-- NH$_3$, HNO$_3$, H$_2$O$_2$, etc.

-- They might dissolve in the particle water and be concentrated with the particles
Why Perform this Study?

We use VACES for our Concentrated Ambient Particle studies (CAPS)

We have had problems maintaining the concentrating factor although our clever operators frequently overcome them
Physical Characterization

HEPA filter ambient air to remove particles

Generate and Inject Test Particles

Measure Particle Size Distribution before and after VACES

Measure other Physical Conditions of VACES
Physical Characterization

Good Performance

Enhancement of total numbers, RH, and Temperature

PSL+filtered air

Inlet RH
Outlet RH
Bath T
Outlet T
Inlet T

Enhancement Factor

Heated at 80 VAC

Heated at 86 VAC

Time of 1/25/2006
Physical Characterization

Impactor Clogging

Enhancement of total numbers, RH, and Temperature

PSL+filtered air

Time of 1/27/2006

Enhancement Factor

Inlet RH

Outlet RH

Bath T

Vapor T

Outlet T

Inlet T
Physical Characterization

Size-Dependent and Variable Enhancement Factor

Particle size (nm)

PSL
Ammonium sulfate
Ambient particles
Oleic acid
Chemical Characterization

HEPA filter ambient air to remove particles

Generate and Inject Test Particles

Generate and Inject Test Gases (NH$_3$, HNO$_3$, H$_2$O$_2$)

Collect Particles before and after VACES

Collect Gases before and after VACES
## Chemical Characterization

### Hydrogen Peroxide

<table>
<thead>
<tr>
<th>Date</th>
<th>Run #</th>
<th>Gas Phase H$_2$O$_2$ Outlet/Inlet</th>
<th>EF by Particle Number Concentration</th>
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<td>3</td>
<td>0.48</td>
<td>2</td>
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<td>4</td>
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<td>2</td>
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<td>Ave</td>
<td>0.40 ± 0.1</td>
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<tr>
<td>18-Mar</td>
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<td>6</td>
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<td>6</td>
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<td>3</td>
<td>0.61</td>
<td>6</td>
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<td>3</td>
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<td>Ave</td>
<td>0.50 ± 0.1</td>
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</table>
## Chemical Characterization

### Ammonia and Nitric Acid

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<th>Expt #</th>
<th>Date</th>
<th>HEPA Particle filter</th>
<th>Aerosol</th>
<th>HNO₃ source</th>
<th>RH&lt;sub&gt;out&lt;/sub&gt; (%)</th>
<th>EF(Number)</th>
<th>EF(NH₃)</th>
<th>EF(HNO₃)</th>
<th>N&lt;sub&gt;inlet&lt;/sub&gt;</th>
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<td>MgSO₄</td>
<td>N</td>
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<td>MgSO₄</td>
<td>N</td>
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<td>11</td>
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<tr>
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<td>MgSO₄</td>
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<td>(NH₄)₂SO₄</td>
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<td>Y (70°C)</td>
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<td>Y (60°C)</td>
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<td>7.2</td>
<td>3.3</td>
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</tbody>
</table>
Improved VACES (iVACES)

Engineering Problems
1) A reduction in inlet flow may collapse the water bath due to pressure drop in the system.
2) Water in the bath may completely evaporate destroying the heater and/or cause a fire.
3) The ceramic bath heater is easy to break.
4) Bath water must be replaced manually.
5) Water accumulates in the virtual impactor, which must be removed and emptied periodically, limiting continuous operation time.
Improved VACES (iVACES)

Functional Problems

6) The concentration enrichment factor depends on ambient temperature, ambient RH and bath temperature, so is less than 10 for a wide range of ambient conditions.

7) High particle inlet concentrations are not concentrated well due to insufficient water vapor to grow all particles sufficiently large for the virtual impactor.

8) The optimum bath temperature depends on the temperature and relative humidity of the input and output air masses.

9) The silica gel dryer saturates, must be replaced daily, and produces an RH that is not ambient.
Improved VACES (iVACES)

Solution to Engineering Problems
1) Pressure drop may collapse the water bath
2) Bath water loss may destroy heater
3) The ceramic bath heater is easy to break
4) Bath water must be replaced manually

New Features
1) Thermostatically controlled water temperature
2) Recirculating pump
3) Warm water reservoir
4) Drain valve to replace de-ionized bath water
5) Half-filled pipe to warm, humidify air
Improved VACES (iVACES)

- Water Fill
- Humidifier
- Water Reservoir
- Water Heater
- Hot Water Reservoir
- Drain port
Improved VACES (iVACES)

Solution to Engineering Problem
5) Water accumulates in the virtual impactor, which must be removed and emptied periodically, limiting continuous operation time.

New Feature
1) Drain added to virtual impactor
Improved VACES (iVACES)

Engineering Improvements
• Modularize the system so that it can be scaled to the experimental need

New Features
1) Employ 100 LPM channel modules
2) Use Variable Frequency Drive (VFD) on the major flow pump so that can be easily adjusted to the flow need
3) The VFD shuts the system down if the pressure drops below a preset to protect the rest of the system
Improved VACES (iVACES)
Improved VACES (iVACES)

Functional Problems
9) The silica gel dryer saturates, must be replaced daily, and produces a RH that is not ambient.

New Feature
1) Counterflow Nafion dryer to bring T and RH close to ambient
Improved VACES (iVACES)

![Graph showing the enrichment factor over time for different dates: 12/29/2009, 1/3/2010, and 1/5/2010. The x-axis represents the time of the day, from 9:00:00 to 23:00:00, and the y-axis represents the enrichment factor (number). The graph shows fluctuations in the enrichment factor throughout the day for each date.]
Improved VACES (iVACES)

Enhancement Factor > 15
Size Independent

![Graph showing concentrated and ambient particles size distribution](image-url)
Thanks to

- Great collaborators for doing all the work
- CARB for financial and moral support

Questions?