# 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

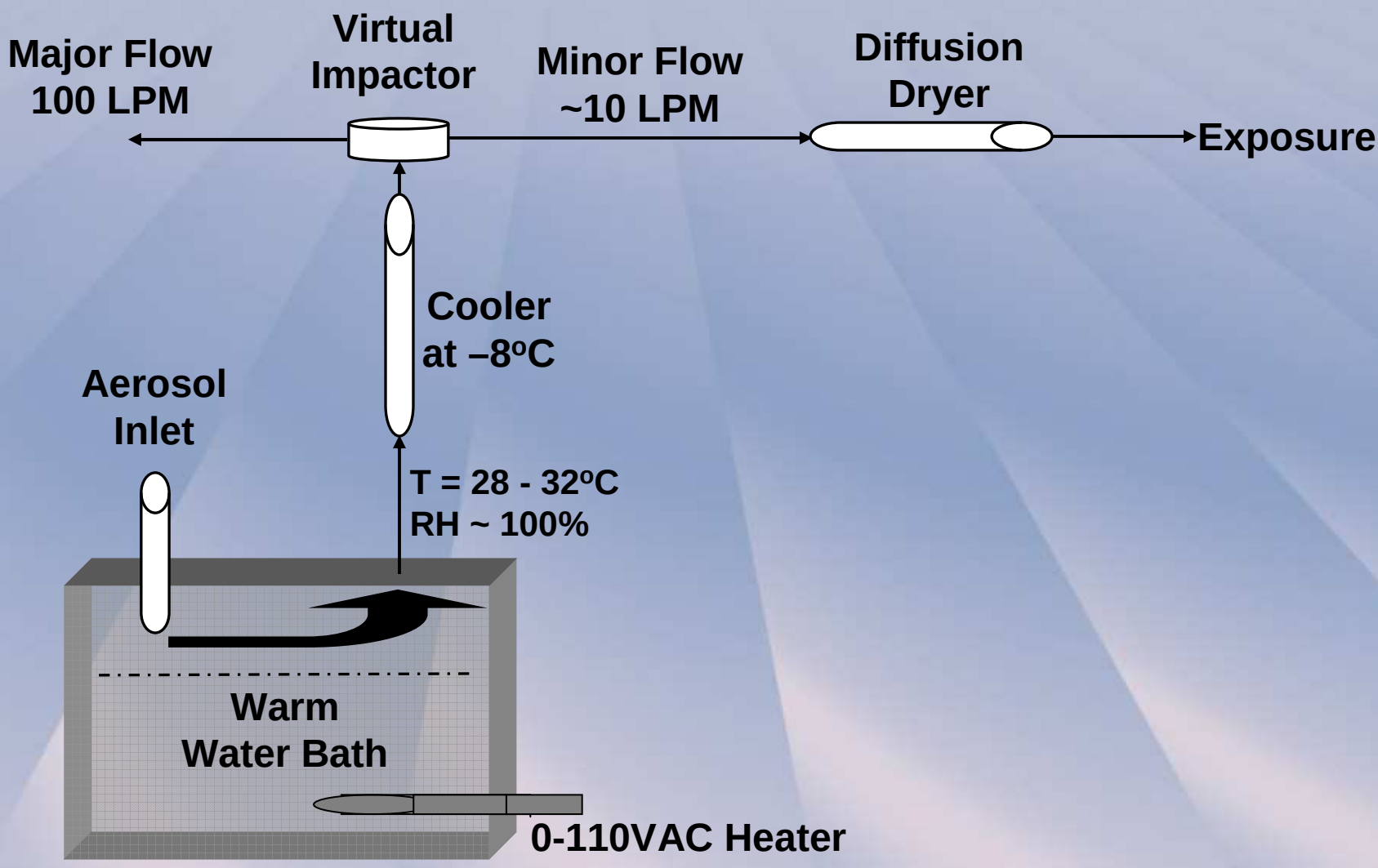
-- Warm, humidify, saturate incoming ambient air

-- 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?



# 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

-- $NH_3$, $HNO_3$, $H_2O_2$, 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

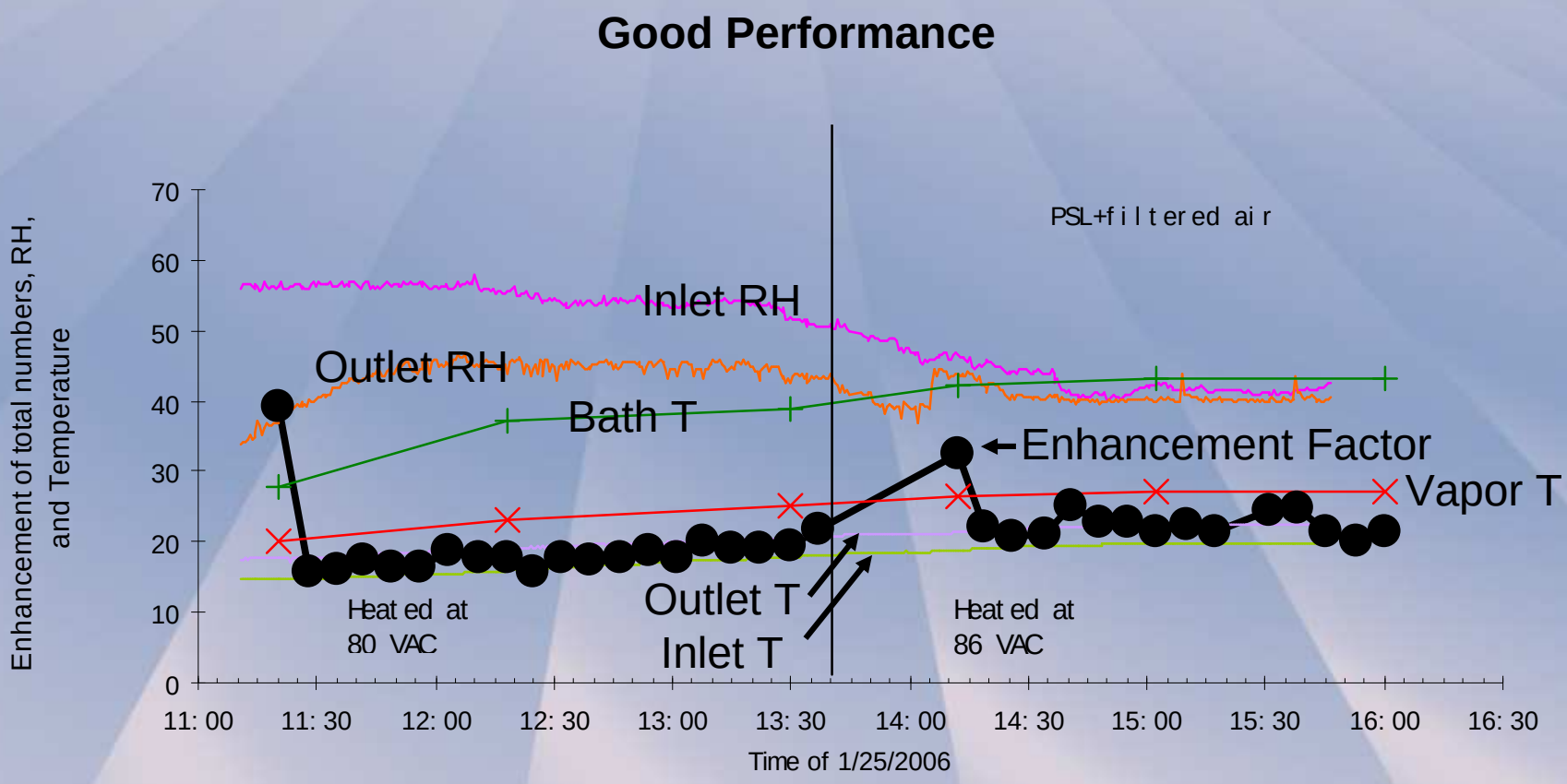
HEPA filter ambient air to remove particles

Generate and Inject Test Particles

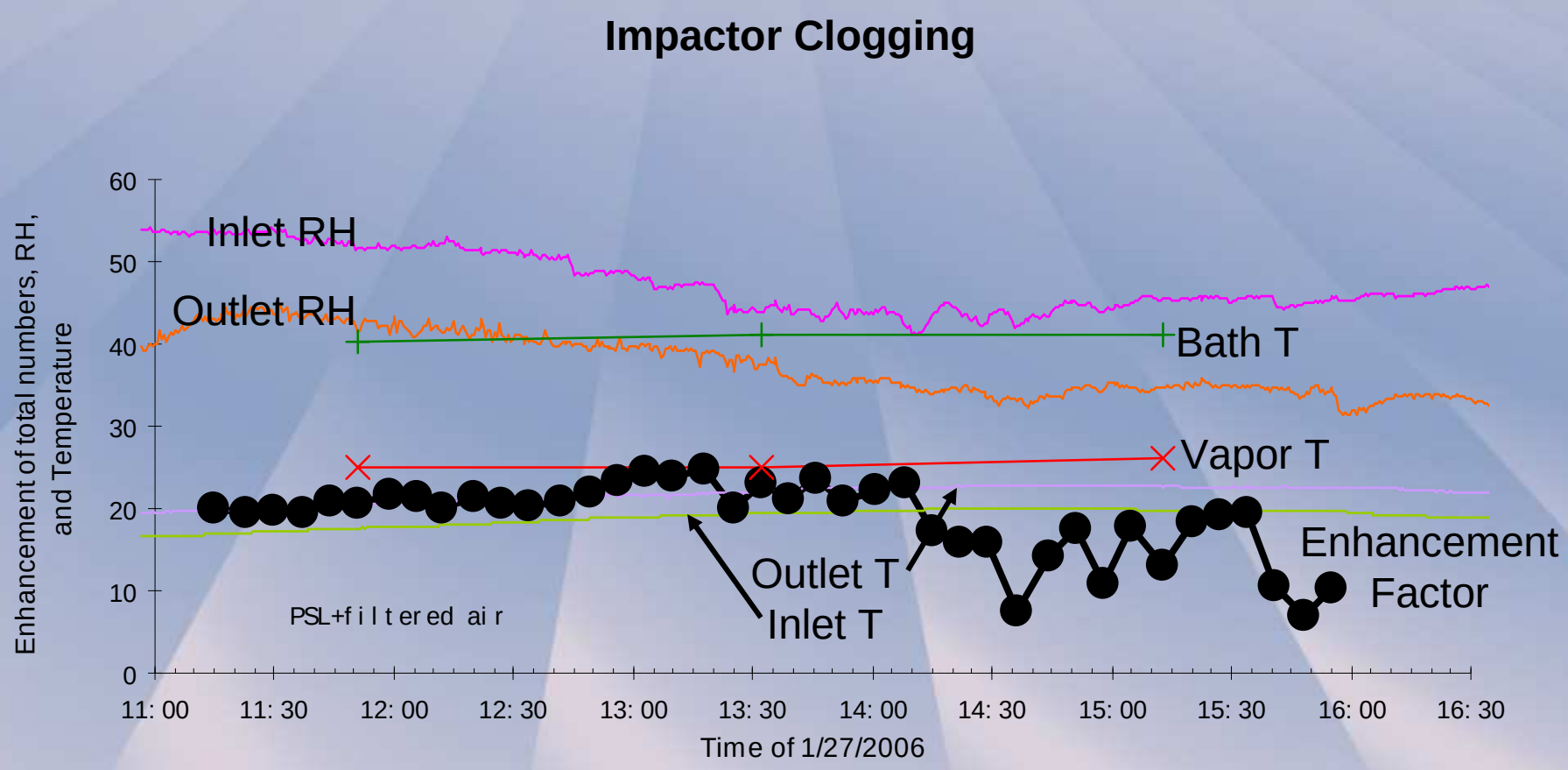
Measure Particle Size Distribution before and after VACES

Measure other Physical Conditions of VACES

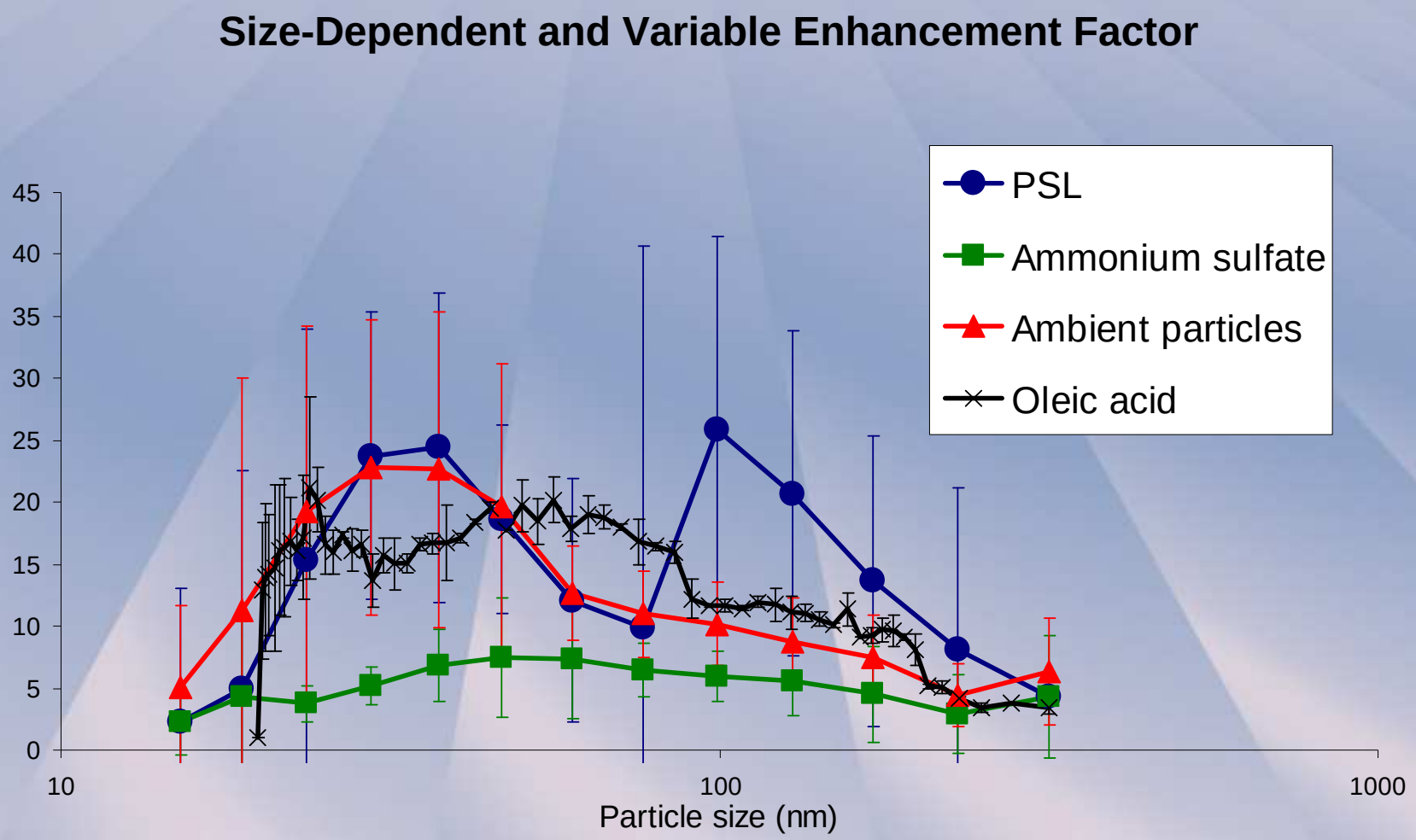
# Physical Characterization



# Physical Characterization



# Physical Characterization



# Chemical Characterization

HEPA filter ambient air to remove particles

Generate and Inject Test Particles

Generate and Inject Test Gases ($NH_3$, $HNO_3$, $H_2O_2$)

Collect Particles before and after VACES

Collect Gases before and after VACES

# Chemical Characterization

## Hydrogen Peroxide

| Date | Run # | Gas Phase $H_2O_2$ Outlet/Inlet | EF by Particle Number Concentration |
|---|---|---|---|
| 16-Mar | 1 | 0.27 | 10 |
| | 2 | 0.38 | 5 |
| | 3 | 0.67 | 2 |
| | 4 | 0.55 | 1 |
| 17-Mar | 1 | 0.43 | 7 |
| | 2 | 0.23 | 2 |
| | 3 | 0.48 | 2 |
| | 4 | 0.35 | 2 |
| **Ave** | | **0.40 ± 0.1** | **4** |
| 18-Mar | 1 | 0.63 | 6 |
| | 2 | 0.58 | 6 |
| | 3 | 0.61 | 6 |
| | 4 | 0.48 | 3 |
| | 5 | 0.58 | 6 |
| | 6 | 0.65 | 4 |
| | 7 | 0.39 | 3 |
| **Ave** | | **0.50 ± 0.1** | **5** |

# Chemical Characterization

## Ammonia and Nitric Acid

| Expt # | Date | HEPA Particle filter | Aerosol | $HNO_3$ source | $RH_{out}$ (%) | EF(Number) | EF($NH_3$) | EF($HNO_3$) | $N_{inlet}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 28-Mar | N | ambient | N | 29.4 | -- | 1.1 | -- | -- |
| 2 | 15-Mar | N | ambient | N | 47.8 | 10 | 2.2 | -- | -- |
| 3 | 13-Feb | N | ambient | N | 21.3 | 6.6 | 1 | 0.075 | -- |
| 4 | 13-Feb | N | ambient | N | 15.6 | -- | 1.7 | 0.19 | -- |
| 5 | 28-Mar | Y | N | N | 26.5 | -- | 1 | -- | -- |
| 6 | 15-Mar | Y | N | N | 33.4 | -- | 0.9 | -- | -- |
| 7 | 21-Mar | Y | $MgSO_4$ | N | -- | 7 | 3 | -- | 1.70E+04 |
| 8 | 21-Mar | Y | $MgSO_4$ | N | -- | 4.7 | 2.3 | -- | 1.30E+04 |
| 9 | 7-Mar | Y | $MgSO_4$ | N | 33.5 | 11 | 1.4 | -- | 8.80E+02 |
| 10 | 7-Mar | Y | $MgSO_4$ | N | 28.8 | 8.6 | -- | -- | 9.10E+02 |
| 11 | 28-Feb | Y | $(NH_4)_2SO_4$ | N | 44.5 | 4.9 | 1.7 | -- | 7.30E+04 |
| 12 | 28-Feb | Y | $(NH_4)_2SO_4$ | N | 34 | 4.2 | 0.95 | -- | 2.50E+03 |
| 13 | 24-Jan | Y | $(NH_4)_2SO_4$ | Y (70℃) | 47.4 | 4.9 | -- | 0.1 | -- |
| 14 | 12-Jan | N | $(NH_4)_2SO_4$ | Y (60℃) | -- | 7.2 | 3.3 | -- | -- |

# Improved VACES (iVACES)

Engineering Problems

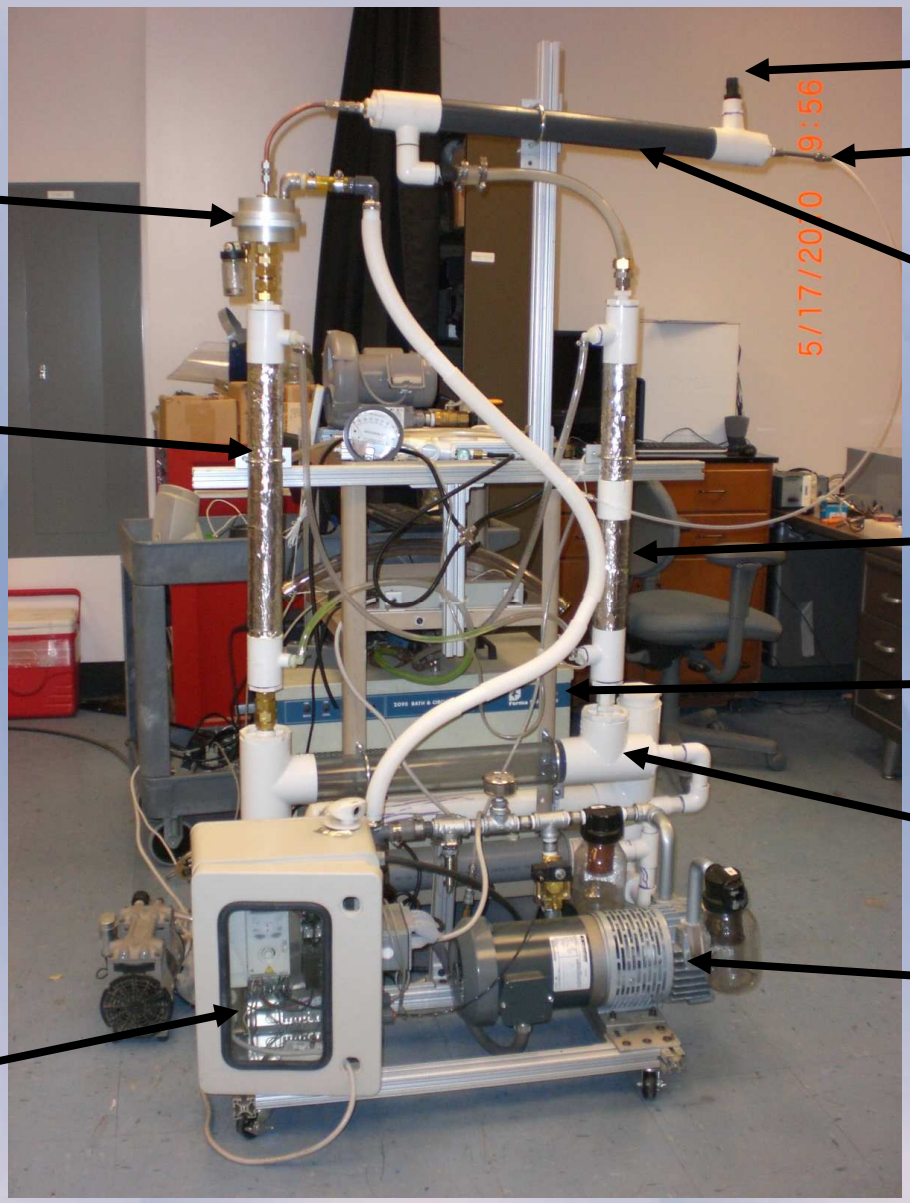
1) A reduction in inlet flow may collapse the water bath due to pressure drop in the system.
2) Water in the bath may completely evaporate destroying the heater and/or cause a fire.
3) The ceramic bath heater is easy to break.
4) Bath water must be replaced manually.
5) Water accumulates in the virtual 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)




Virtual Impactor

Cooler

VFD

Inlet

Outlet

Counterflow Nafion Dryer

Pre-Cooler

Refrigerator

Humidifier

Pump

# Improved VACES (iVACES)

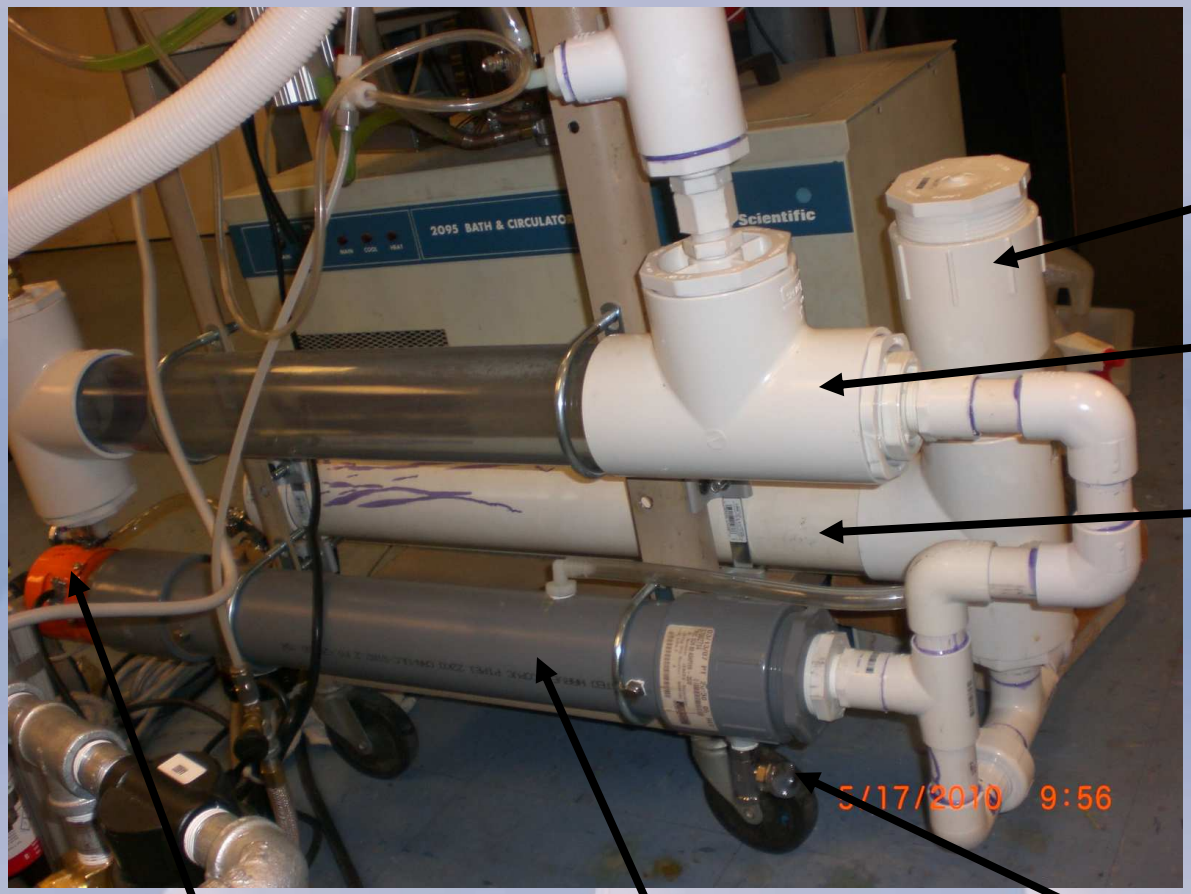
Solution to Engineering Problems

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)



# 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)

Drain

# Improved VACES (iVACES)

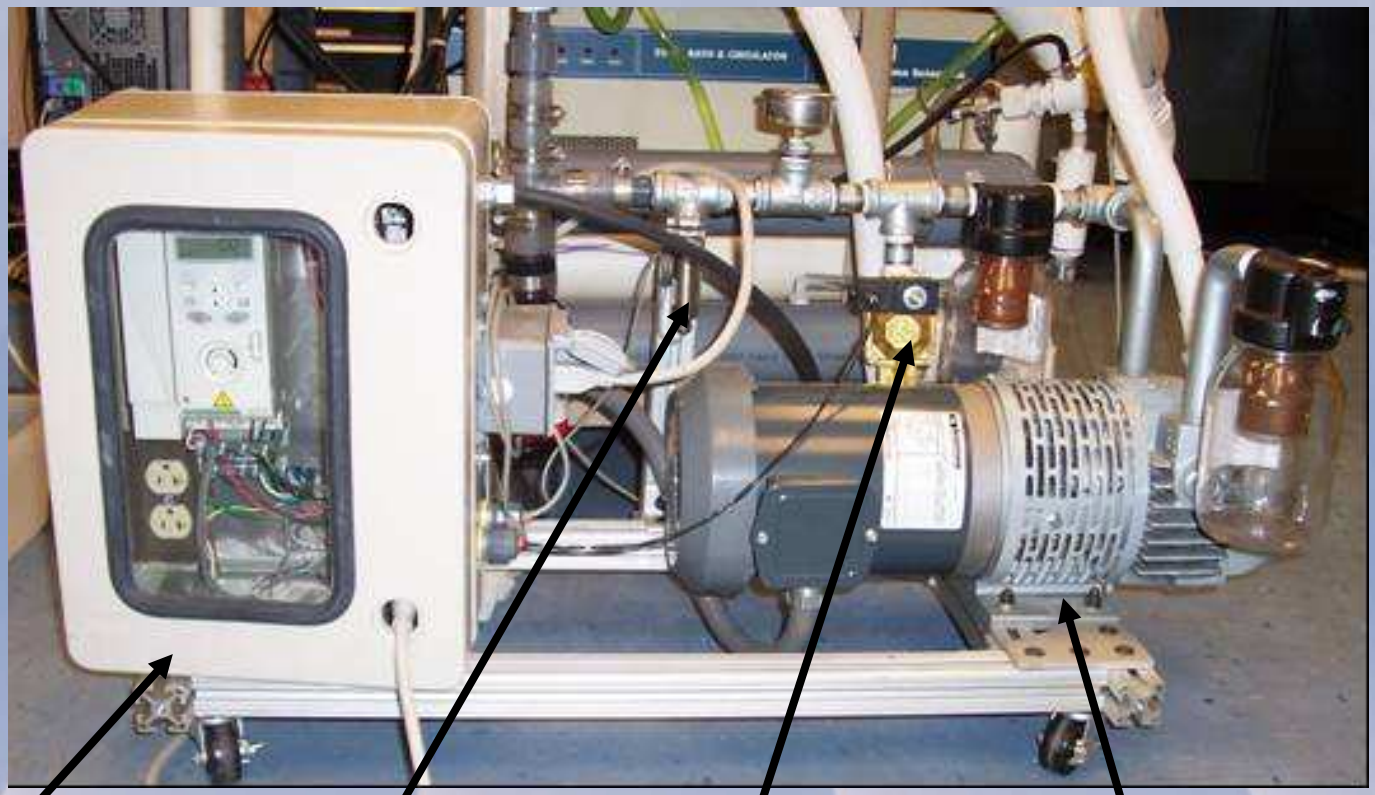
Engineering Improvements

- 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)



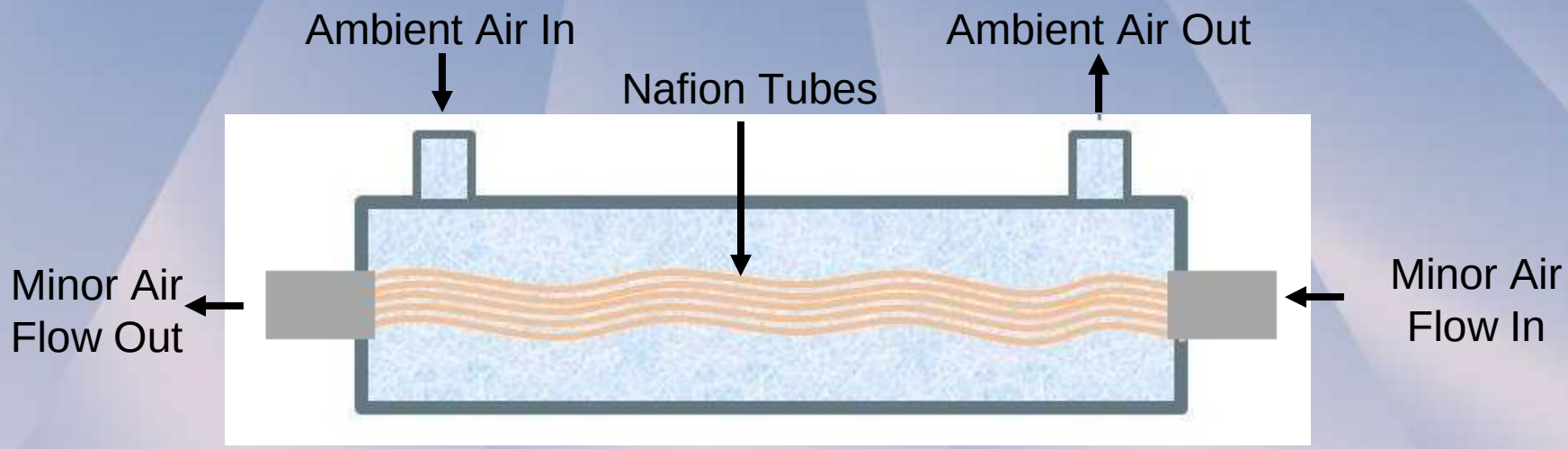
# Improved VACES (iVACES)

Functional Problems

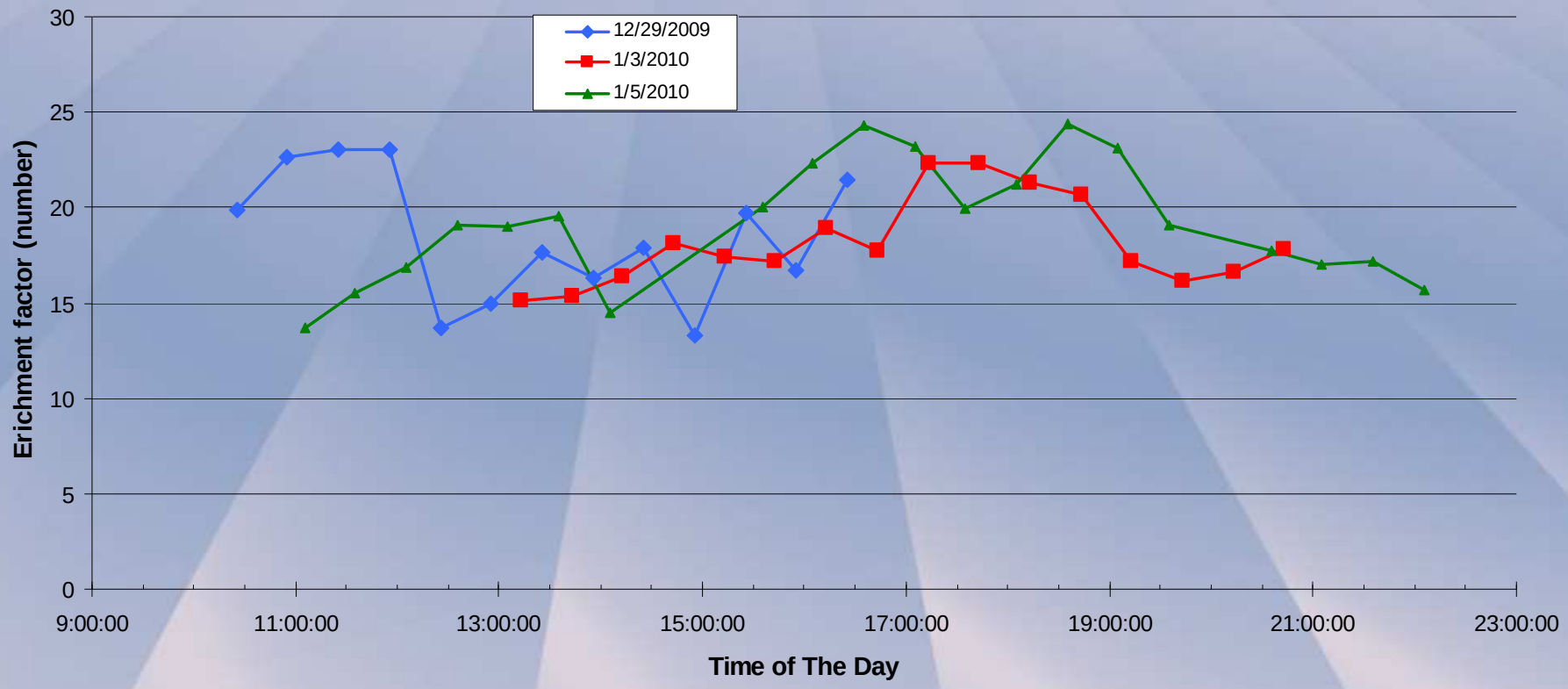
9) The silica gel dryer saturates, must be replaced daily, and produces a RH that is not ambient.

New Feature

1) Counterflow Nafion dryer to bring T and RH close to ambient



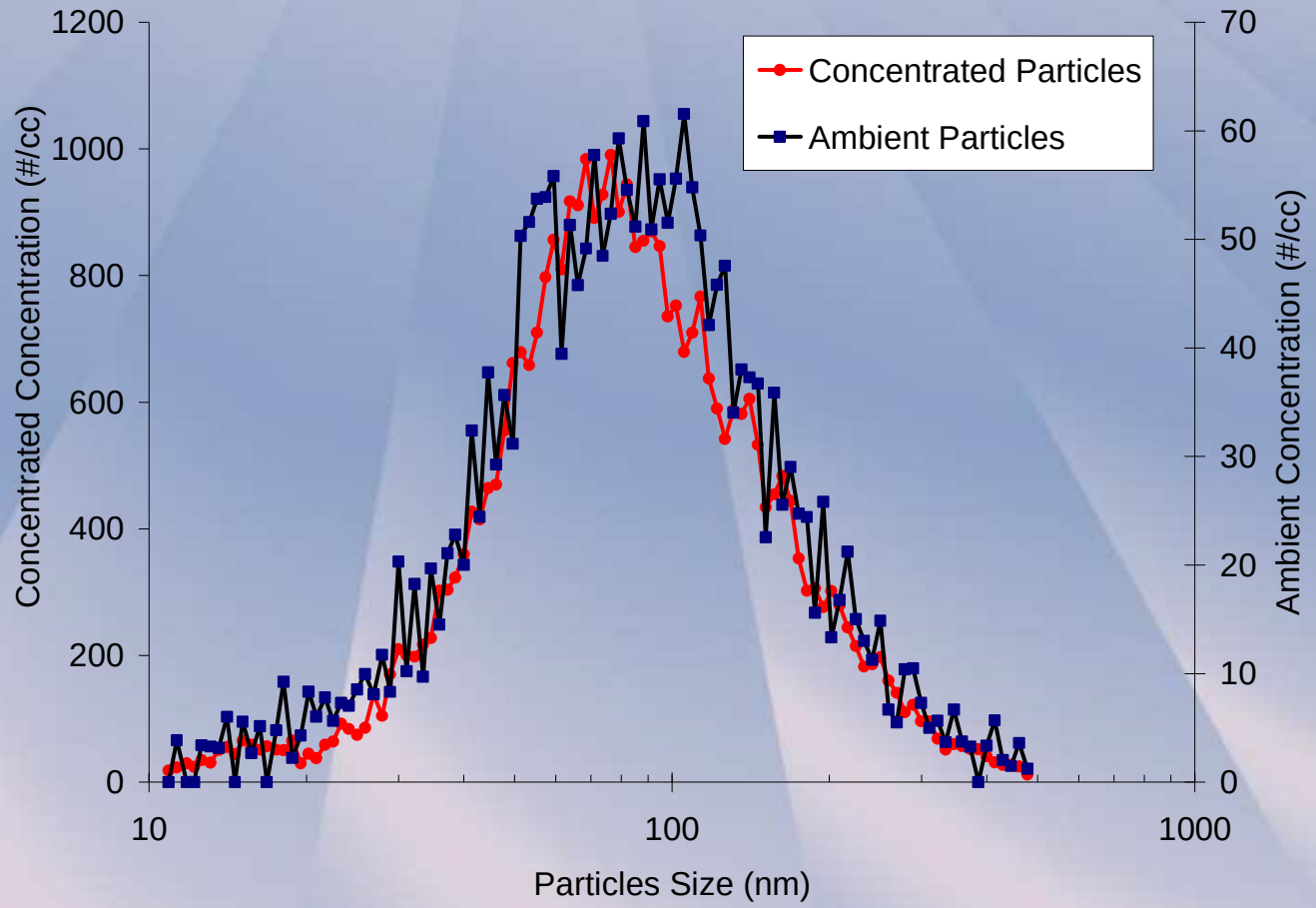
# Improved VACES (iVACES)



# Improved VACES (iVACES)

Enhancement Factor > 15

Size Independent



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**Questions?**