Development of Personal Aerosol Collector and Spectrometer (PACS): Part I: Design and Theory

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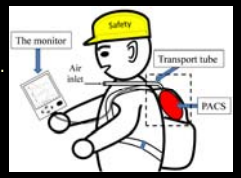
Background

- People are exposed to a variety of particles with a wide range of sizes.
- Current personal samplers cannot measure real-time exposures to all particle size ranges simultaneously.
- Need to simultaneously measure particle number, surface area, and mass concentrations by size and collect particles for subsequent chemical analysis from 10 nm to 10 μm.

Objective

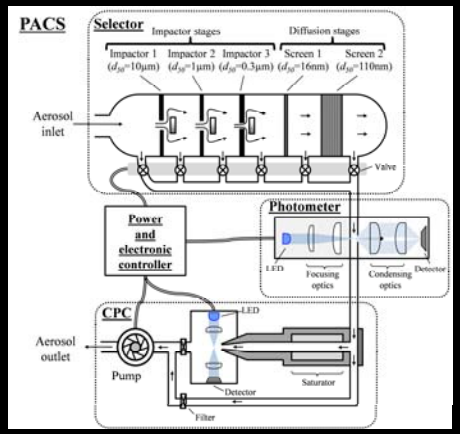
- Describe the Personal Aerosol Collector and Spectrometer (PACS).
- Describe and test the algorithm used to fit tri-modal distributions with PACS data.

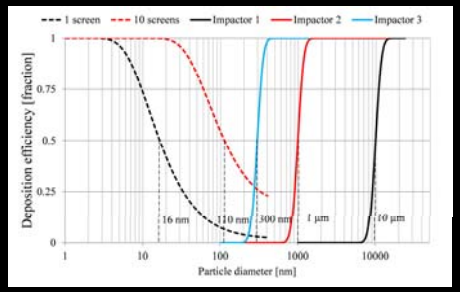


Methods

PACS hardware

- Combines three devices: selector, photometer and condensation particle counter (CPC).
- Detects particle number and mass concentrations after passing through selector stages.





Deposition efficiencies of PACS components

PACS software

Fits a tri-modal, log-normal distribution to the number and mass concentrations measured after the size selector as shown below.

Inputs: Measured number and mass concentrations in each stage (6 sets)

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Step 1: Iterate geometric standard deviation (GSD) and count median diameter (CMD) for each mode to obtain initial values (using parallel computing and low iteration resolution could decrease the computation time)

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Step 2: Use Hatch-Choate equations to find average mass diameter (AMD), mass median diameter (MMD) and surface area median diameter (SMD) for each mode

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Step 3: Acquire the number concentrations by solving the constrained linear least-square problem, which could dramatically decrease the computation time

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Step 4: Save all calculated CMDs, GSDs and number concentrations that satisfy the following condition: the difference between calculation and measurement is less than 10% for each stage

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Condition 1: If the results exit

Step 5a: Calculate the averaged value of each parameter in Step 4

Condition 2: If the results do not exit

Step 5b: Calculate each parameter in Step 4 by finding the minimum squared sum of relative error (SSRE)

↓

Outputs: (1) The number concentrations, surface areas, mass concentrations, CMD, SMD, MMD, AMD and GSD for each mode; (2) The particle size distribution plots

Four cores (i7- 4790 processor) were used in parallel computing in this study.

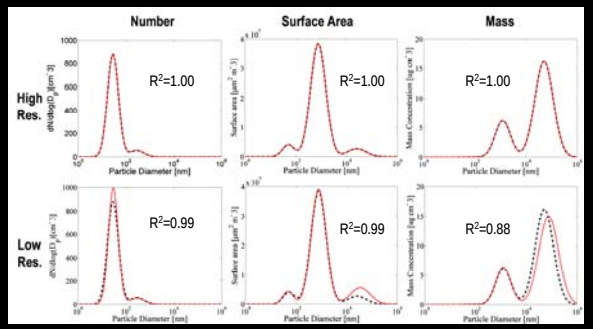
The low resolution iteration decreased the time by ~1/729,000.

Optimization method reduced three loops in the algorithm, which could decrease the time by ~1/1,000,000.

The performance was evaluated using the normalized mean bias (NMB) and R^2.

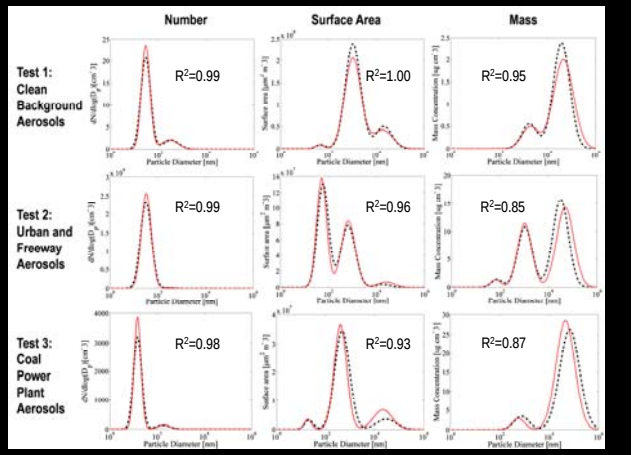
Results

Tests using High Res. vs. Low Res. for typical atmospheric size distribution



- High resolution iteration found the exact log-normal distribution parameters; however, the time was unacceptably long (~500 days).
- Low resolution iteration found similar results with much shorter computation time (~110 seconds).

Tests for pre-defined aerosols



- NMB was used to evaluate the tendency of the algorithm to over-estimate or under-estimate variables; R^2 was used to indicate how well data fit a statistical model.
- For number concentrations: NMBs = 0%, R^2 = 0.98 to 0.99.
- For surface area concentrations: NMBs = 0% to 7%, R^2 = 0.93 to 1.00.
- For mass concentrations: NMBs = 0%, R^2 = 0.85 to 0.95.

Conclusions

- The PACS introduced:
  - Selector differentiates particles by size and collect particles for chemical analysis
  - Software fit a tri-modal, log-normal distribution to number and mass concentration data measured downstream of selector
- Software fit the size distributions well for diverse pre-defined aerosols.
- Software computation time was decreased to ~110 seconds using the optimization method, low resolution iteration and parallel computing.

References

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