Compact, High-flow, Water-based, Turbulent-mixing, Condensation Aerosol Concentrator for Collection of Spot Samples_Dataset

Introductory Information

A new high-flow, compact aerosol concentrator, using rapid, turbulent mixing to grow aerosol particles into droplets for dry spot sample collection, has been designed and tested. The "TCAC (Turbulent-mixing, Condensation Aerosol Concentrator)" is composed of a saturator for generating hot vapor, a mixing section where the hot vapor mixes with the cold aerosol flow, a growth tube where condensational droplet growth primarily occurs, and a converging nozzle that focuses the droplets into a beam. The prototype concentrator utilizes an aerosol sample flow rate of 4 L min^{-1}. The TCAC was optimized by varying the operating conditions, such as relative humidity of the aerosol flow, mixing flow ratio, vapor temperature, and impaction characteristics. The results showed that particles with a diameter ≥ 25 nm can be grown to a droplet diameter > 1400 nm with near 100 % efficiency. Complete activation and growth were observed at relative humidity ≥ 25 % of the aerosol sample flow. A consistent spot sample with a diameter of D_{90} = 1.4 mm (the diameter of a circle containing 90 % of the deposited particles) was obtained regardless of the aerosol particle diameter (d_p = 20 – 1900 nm). For fiber counting applications using phase contrast microscopy, the TCAC can reduce the sampling time, or counting uncertainty, by two to three orders of magnitude, compared to the 25-mm-filter collection. The study shows that the proposed mixing-flow scheme enables a compact spot sample collector suitable for handheld or portable applications, while still allowing for high flow rates.

Experimental Methods

Experiments were designed and conducted for the evaluation of the TCAC based on the following key variables:

(i) The mixing ratio of the vapor flow rate to the aerosol flow rate (Q_h/Q_c),

(ii) The saturator temperature (T_h),

(iii) The relative humidity of the aerosol flow,

(iv) The particle diameter (d_p) of the sampled aerosol, and

(v) The number concentration of the sampled aerosol.

The dry spot diameter and particle radial distribution were also estimated by collecting particles on a substrate downstream of the concentrator. The counting statistics for fiber count measurement using optical microscopy were acquired for the TCAC and compared with the calculated counting statistics promoted by the Sequential Spot Sampler, and the conventional technique of air filtration.

<u>Particle generation:</u>

Particles were generated by a *nebulizer*.

❖ *Nebulizer* (Salter 8900 Series Disposable Small Volume Jet Nebulizer; Salter Labs, Arvin, CA, USA):

- Liquid solutions of sodium chloride were used.
- A diffusion dryer (model 3062, TSI Inc., Shoreview, MN, USA) was used downstream of the nebulizer for removal of water vapor.

Particle classification:

- The Aerodynamic Aerosol Classifier (AAC; Cambustion Ltd, Cambridge, United Kingdom) was used to obtain classified near-monodisperse (in aerodynamic size) test aerosol with $d_p \geq 25$ nm.
- Dry, particle-free, dilution air was added downstream of the AAC to increase the total aerosol flow rate at 4 L min^{-1}, which was introduced into the TCAC.
- Particle-free flow was introduced into the saturator of the TCAC to generate hot saturated flow. The saturator temperature was set to 70 – 85 °C, at a flow rate of 0.2 – 1.2 L min^{-1}.
- The humidity of the aerosol flow was varied using a commercial Nafion™ humidifier (model MH-110-12F-4; Perma Pure LLC, NJ, USA) to control the *RH* in the range 10 – 100 %.

Activation efficiency measurements:

- The particle/droplet number concentration downstream of the TCAC was measured using two optical counters, connected in parallel: the Ultrafine Water-based Condensation Particle Counter (model 3786 UCPC; TSI Inc., Shoreview, MN, USA) and the Optical Particle Sizer (model 3330 OPS; TSI Inc., Shoreview, MN, USA). The tubing connecting the TCAC to the optical counters was shielded. The length of tubing from the TCAC to the inlet of OPS and UCPC were kept identical to ensure similar transport losses.
- The UCPC provided a total number concentration of particles with a diameter as small as 2.5 nm.

- The OPS classified particles into 16 different channels in the size range of 300 nm to 10 µm based on their optical diameter.

<u>Droplet Optical Diameter (d_d) and Aerodynamic Diameter (d_p)</u>:

- For this study, it was assumed that the minimum collectable diameter (at which particles could be collected by impaction) was approximately ≥ 1.4 µm optical diameter (d_d).
- Optical particle counters are typically calibrated with PSL spheres, which have a refractive index of 1.6.
- A pure water droplet has a refractive index of 1.33. As a result, water droplets are expected to appear undersized when detected by optical counters (Hinds and Kraske 1986; Garvey and Pinnick 1983; Pinnick et al. 1981).
- In this study, NaCl particles with an aerodynamic diameter (d_p) of ≥ 25 nm, were enlarged into droplets with d_d > 1400 nm. Assuming that the droplets were spherical, and made of pure water, the aerodynamic diameter was estimated to be 1.8 µm from Chien et al. (2016). However, the equation provided by Chien et al. (2016) was developed for oleic acid aerosols, which have a refractive index of 1.46, lower than that of PSL but larger than that of water. Therefore, the actual aerodynamic diameter of the water droplets is expected to be larger than 1.8 µm.
- As a result, the activation efficiency estimated in this study was based on optical diameters greater than 1.4 µm (unless stated otherwise).

Deposit diameter:

- Polystyrene nanospheres of 20 and 150 nm diameter (NIST Traceable Size Standards, Thermo Fisher Scientific) and 1.9-µm-diameter fluorescent beads (fluoro-max green beads; Thermo Fisher Scientific) were used.
- The particulate sample was collected on a flat heated surface at 90 – 100 °C ($T_{substrate}$), and at the optimum nozzle-to-plate distance determined experimentally.
- The particles were collected directly on an aluminum-backed, carbon tape (product 16086-5; Ted Pella Inc., Redding CA, US) that could be readily analyzed using Scanning Electron Microscopy (SEM; Phenom XL Desktop SEM, Thermo Fisher Scientific) to obtain the dry spot diameter and the particle distribution characteristics within the spot.
- The ImageJ software was implemented for measuring the projected area of the accumulated particles depicted on the SEM images.
- The dry spot diameter, defined as the diameter of the circle encompassing 90 % of the deposited particles, was calculated by determining the radial distribution of the projected area of the collected particles on the substrate.

Number Concentration Effect:

- The number concentration of the test aerosol at the inlet of the concentrator was varied to investigate its impact on the performance of the TCAC.
- Dilution flow or make-up air was used to achieve the desired number concentrations.
- To minimize any effects on the performance of the concentrator due to the dilution, the mixing ratio was kept constant across the range of number concentrations tested.

Poisson Counting Statistics of Fiber Concentration Measurement

- Calculations were performed to compare Poisson counting statistics of fiber concentration measurement using the phase contrast microscopy (PCM; NIOSH Method 7400) for various collection methods, such as TCAC, Sequential Spot Sampler and filter-based collection.

Citations- Publications based on the dataset

Zervaki, O., Dionysiou, D. D., & Kulkarni, P. (2024). Compact, high-flow, water-based, turbulent-mixing, condensation aerosol concentrator for collection of spot samples. *Aerosol Science and Technology*, *58*(8), 889–901. https://doi.org/10.1080/02786826.2024.2361050

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