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Method and apparatus for quantitative measurement of aerosol composition using controlled collection of airborne particles

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It is important to characterize the composition of aerosol particles in air, which causes adverse health effects and millions of deaths each year. Aerosol, or particulate matter (PM), is difficult to characterize because of its wide range of particle sizes; constituents (various organic and inorganic compounds); concentration; morphology; state (liquid or solid); and time-dependent modification. Infrared (IR) spectroscopy is a non-destructive method, which provides useful chemical information about the constituents. Current methods for collecting samples use filters that are made of materials which interferes with the IR spectra and thus lowers detection capabilities. Hence, collection on an IR-transparent substrate is desirable. In order to make a good quantitative measurement of the composition of the aerosol using IR-spectroscopy, a collector design should achieve some objectives. Low size-dependence, low chemical interference, and high collection efficiency are required to collect an aerosol sample that is identical to the aerosol in air. Furthermore, high spatial uniformity in deposition pattern is required to reduce optical artefacts or spectrometer dependence, and high collection mass flux is required to reduce the collection time needed for making a confident claim.

Electrostatic precipitation (ESP) is a versatile method of aerosol collection and does not suffer from high pressure drop (which can modify the aerosol chemical composition, for example in filtration), or from bounce-off effects (which preferentially samples the size range and liquids, for example in impaction). ESP devices for particle deposition are present in either a translationally symmetric design (linear system) or a radially symmetric design (radial system). Most ESP designs in the public domain have been designed for different purposes and face limitations for fulfilling objectives stated above. Hence, a new device is necessary to meet performance objectives.

Our design is based on an analytical, dimensionless (scalable) mathematical model that embodies the physics of particle migration trajectories due to fluid dynamics and electrostatics that lead to particle capture in a two-stage ESP device. This model allowed us to evaluate the tradeoffs among objectives to arrive at a design optimized across multiple objectives, and across multiple length scales (due to its dimensionless form). We validated this model against numerical simulations using COMSOL Multiphysics software, which is considered to be accurate but can only be run for a limited number of configurations (with respect to geometry and operating parameters) due to its high computational cost. Using the validated analytical model, we investigate the relationship among device geometry, methods of particle introduction, operational parameters, and deposited particle positions (which determines collection efficiency, uniformity, and size dependence), to arrive at a range of designs that meet design criteria.

We further report the fabrication of a suitable embodiment using 3D-printing while incorporating ease of operation and handling. Measurement capabilities and limits of the device using different laboratory-generated aerosol are reported.