Supplementary Information

A Cost-Effective Electrostatic Precipitator for Aerosol Nanoparticle Segregation

S. Bezantakos, L. Huang, K. Barmounis, M. Attoui, A. Schmidt-Ott and G. Biskos

S1. Supporting equations for the EDM-tube penetration model

The diffusion coefficient and the electrical mobility of the particles are respectively given by:

$$D = \frac{kTC_c}{3\pi\eta d_p}, \quad (S1)$$

$$Z_p = \frac{neC_c}{3\pi\eta d_p}, \quad (S2)$$

where k is the Boltzmann constant (1.38×10^{-23} J/K), T is the absolute temperature ($T = 298$ K for all the calculations described in the letter), η is the air viscosity (1.81×10^{-5} kg/ms), e is the electron charge (1.6×10^{-19} C), n is the number of elementary charges on the particles, d_p is the particle diameter and C_c is the Cunningham slip correction factor given by:

$$C_c = 1 + \frac{\lambda}{d_p} \left(2.34 + 1.05 \exp \left(-0.39 \frac{d_p}{\lambda} \right) \right). \quad (S3)$$

Here λ is the air mean free path (66×10^{-9} m at atmospheric pressure).

S2. Details of the custom-made DMA used in our experiments

A cylindrical DMA having 0.935 and 1.9575 cm inner and outer radii, respectively, and an effective length of 11.47 cm was used in all the measurements. The sheath flow of the DMA was driven by a controlled closed loop system which included a blower, a heat exchanger, a pressure transducer connected to a laminar flow element for measuring the flow, and a PID controller. A 1:10 aerosol-to-sheath-flow ratio was used throughout all the experiments.

S3. Comparison EDM-tube and Parallel-Plate ESPs

Figure S1 compares EDM-tube penetration efficiency curves predicted by Eq. 1 with corresponding curves (i.e., exhibiting the same cut-off diameters at 50% penetration, d_{50}) for a parallel plate electrostatic precipitators having the same cross-sectional area as predicted by the modified Deutsch-Anderson equation (Leonard *et al.*, 1967).

Fig. S1. Comparison between predicted penetration efficiency curves of the EDM tube (solid lines) and of a parallel plate electrostatic precipitator using the modified Deutsch-Anderson equation (dashed lines). For the calculations we assumed that both instruments have the same cross sectional area (i.e., 32.15 mm²) and operate at the same flow rates: (a) 0.3 lpm, and (b) 1.5 lpm. All curves intersect at 50% penetration efficiency. The labels on each curve indicate the potential required to obtain 50% penetration efficiency for particles having dry mobility diameters of 10, 15, 20, and 25 nm.

S4. Numerical Model

The electric field inside the EDM tube was numerically simulated using version 4.3b of COMSOL® multiphysics. More specifically, we developed a 2-dimensional axisymmetric model, with the axis of symmetry being the center of the tube (cf. Figure S2a). The boundary conditions included the potential on the intermediate electrode (i.e., $V = 1000$ V) and the grounded inlet and outlet ($V = 0$ V). The resistivity of the EDM tube material was set to 4×10^{10} ohm $\times$ cm, according to the manufacturer. Since the relative permittivity of the specific material is unknown, in the calculations we assumed values that range from 2.0 to 7.0, which are typical for most polyurethanes. Variation of the relative permittivity in this range had a less than 4% influence on the calculated electric field strength.

The strength of the electric field within the tube was determined by solving Poisson's equation:

$$-\nabla \times (\epsilon_0 \nabla V - P) = \rho, \quad (\text{S4})$$

where ϵ_0 is the permittivity of free space, V is the potential, P the polarization of the medium and ρ is the charge density ($\rho = 0$ in our calculations). To solve Eq. S4 we used an extremely fine mesh (ca. 5×10^5 elements) and the multifrontal massively parallel sparse direct solver (MUMPS; COMSOL® multiphysics 4.3b reference manual).

Fig. S2. Predicted electric field strength within the EDM tube when 1 kV is applied on the intermediate electrode. The calculations performed using Comsol multiphysics® show (a) the Geometry, (b) the voltage profile, (c) the axial component E_z , and (d) the radial component E_r of the electric field. Zones 1 and 2 respectively denote the region upstream and downstream the intermediate electrode where the high voltage is applied, while the "Hot Spots" indicate locations where E_r is significantly stronger compared to the rest of the area within the EDM tube. Note: The aspect ratio in all plots is distorted to highlight the above-mentioned features, while the arrows are used to illustrate the electric field direction and not its magnitude.

References

- COMSOL® multiphysics version 4.3b. Reference manual. Stockholm, Sweden: COMSOL AB
- Hinds, W. C. (1999). *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*, 2nd Edition. John Wiley & Sons, Inc.
- Leonard, G., Mitchner, M., & Self, S. (1967). Particle transport in electrostatic precipitators. *Atmos. Environ.*, 14:1289–1299.
- Pecht, M. (2000). In “The Electrical Engineering Handbook”. Boca Raton: CRC Press LLC.