Coulombic force contribution to nano scale aerosol capture by a wire grid

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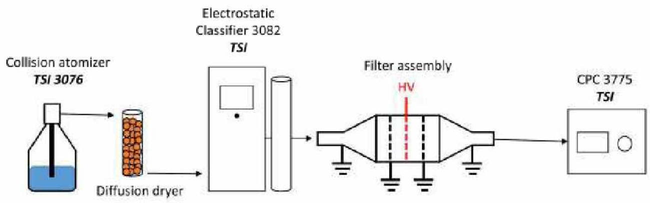
Background

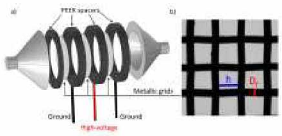
The efficiency of filters at capturing aerosols depends on the aerosol size and typically, filters are least effective at capturing aerosols with diameters between ~100-300 nm—this size range is termed the maximum penetrating particle size (MPPS). Aerosol particles within this size range are particularly hazardous to health since they penetrate deep into human respiratory pathways.

This research work is based on novel experimental and simulation methodologies through which we quantitatively compare electrostatic filtration efficiencies in experiments and first-principle simulations, enabling rigorous understanding of the basis of electrostatic mechanisms on filtration performance.

Material and Methods



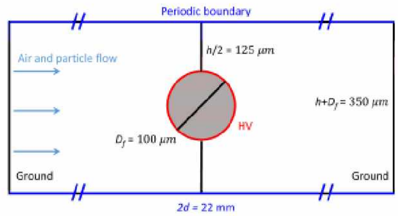
A monodisperse aerosol stream is generated with a controlled charge, by first aerosolizing a solution of monodisperse polystyrene latex (PSL) particles that passes through a differential mobility analyzer to select only the monodisperse PSL particles carrying one elementary charge.



The filter consist of a metallic grid with uniform fiber diameter and spacing. The fiber charge is piloted by applying a potential such that the electric field distribution in our system is always well-defined.

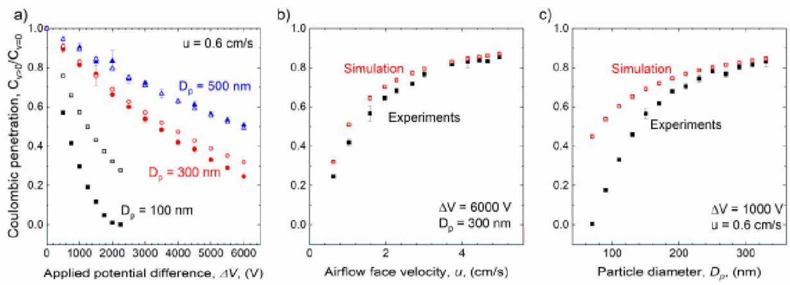
Mechanical and coulombic mechanisms of particle capture are assumed independent : $C_{V=0} = P^{exp}_{mech} C_o$ and $C_{V>0} = P^{exp}_{mech} P^{exp}_{coul} C_o$ where C_o is the constant aerosol concentration upstream the grid.

In simulating the particle trajectories, we consider forces due to the airflow as well as coulombic forces between the particle and fiber. First, we solve the Navier-Stokes equations to determine the laminar fluid flow field and Poisson's equation to determine electrostatic potential field in the system.



The particle trajectories are simulated by integrating Newton's law of motion using COMSOL Multiphysics software. 10,000 particles are considered . The initial positions of the particles are evenly distributed on the left boundary of the simulation cell and with initial velocities equal to the airflow velocity, *u*. As the particles move, if the boundary of the particle contacts the fiber surface, the particle is considered captured by the fiber.

Results

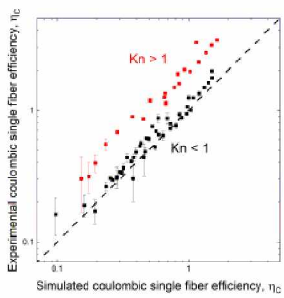


P_{coul} decreases as the applied potential difference increases. This effect occurs because the attractive forces between the particles and fibers increase with greater applied potential differences.

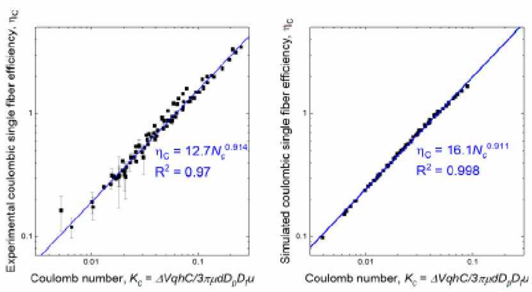
P_{coul} increases as the airflow velocity increases. With higher airflow velocity, the particles spend less time in proximity of the high-voltage grid. Thus, electrostatic forces do not displace particles as significantly toward the fibers and the penetration increases.

P_{coul} increases as the particle diameter increases. As the particle diameter increases, the drag force on the particle increases, which decreases the drift velocity of the particles towards the fiber. Meanwhile the coulombic attractive force between the particles and fibers remain the same since the particle charge is constant.

Conditions where the Knudsen number is less than and greater than 1 can be distinguished.
The Knudsen number is $Kn = 2\lambda/D_p$.



The coulombic penetration predicted from simulations agrees with experiments very well at large particle sizes but overestimates the penetration as the particles size decreases.



A dimensionless coulomb number, K_C, which is the ratio of the drift velocity due to coulomb attraction to the airflow velocity is proposed . The Cunningham slip correction factor, C is included to account for molecular slip.

The comparison between experiments and simulation at small particle sizes indicate the importance of non-continuum, "slip" effects at high Knudsen numbers. This slip, weakens drag forces on aerosol particles, thereby increasing displacement of particles toward fibers due to coulombic forces and consequently improves the filter efficiency.

Conclusions

- We develop an aerosol filtration bench wherein electrical and geometrical properties of both aerosol particles and the filter media are precisely controlled which demonstrate that coulombic interactions significantly enhance filtration efficiency.
- We develop first-principles particle trajectory simulations designed to model our experimental system and find excellent quantitative agreement between simulations and experiments *without any fitting parameters*.
- The combination of the experimental and simulation methodologies developed here elucidate key fundamental physics governing electrostatic filtration and are valuable to examine more complicated phenomena in electret filters such as clogging.