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Electrostatic Precipitator

Modeling and Analytical Verification Concept

Introduction

Electrostatic precipitators are a reliable technology to control emissions of airborne particles covering a substantial range of particle concentrations and sizes.

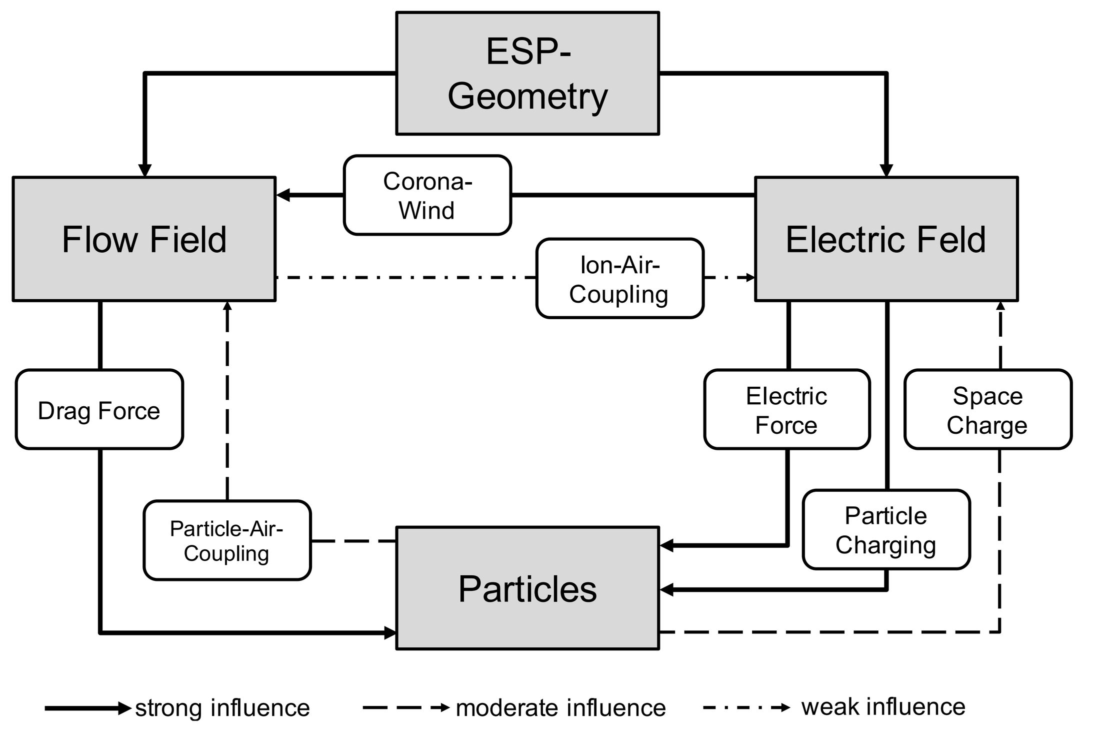


Fig. 1: Interactions in an ESP

Further improvement of ESP focuses on numerical modeling to optimize performance and development costs.

Governing Equations

To correctly take into account the Electrostatics the following four equations need to be fulfilled:

$$\nabla \cdot \boldsymbol{E} = \frac{\rho_{el}}{\varepsilon_0} \quad (1)$$

$$\boldsymbol{E} = -\nabla\phi \quad (2)$$

$$\nabla \cdot \boldsymbol{J} = 0 \quad (3)$$

$$\boldsymbol{J} = \rho_{el}(\boldsymbol{w} + b\boldsymbol{E}) - D\nabla\rho_{el} \quad (4)$$

with the electrical field strength $\boldsymbol{E}$, the space charge density ρ_{el}, the **electrical constant** ε_0, the electric potential ϕ, the current density $\boldsymbol{J}$, the flow velocity $\boldsymbol{w}$, the ion mobility b and the diffusion coefficient D.

For practical implementation equations (1) and (2) as well as (3) and (4) merge to equation (5) and (6), respectively. To analytically verify the wire-tube test case convection and diffusion are neglected, which yields

$$\nabla^2\phi = -\frac{\rho_{el}}{\varepsilon_0} \quad (5)$$

$$\boldsymbol{E}\,\nabla\rho_{el} = -\frac{{\rho_{el}}^2}{\varepsilon_0}. \quad (6)$$

Simulation Setup

Structure

The model consists of three simulations

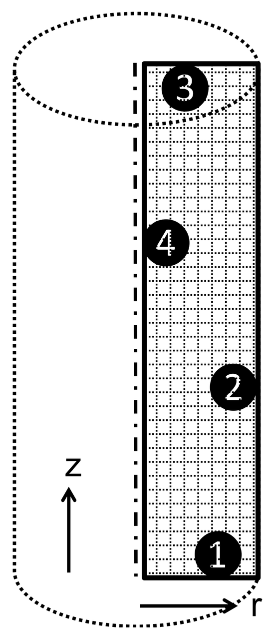
- Stationary flow,
- Stationary electrostatics,
- Transient particle motion.

In the transient simulation the coupling of electrostatics and flow is established through the correspondent acting forces on the particles.

Iteration Algorithm

To calculate the initial space charge density on the emitting electrode a user-operated algorithm is implemented, which is based on the inital current density as fitting parameter. The algorithm performs until the electric field on the electrode matches the expected (given) electric field strength for Corona discharge.

Boundary Conditions



	Boundary	Flow	Electrostatics	Particles
1	Gas Inlet	Velocity profile	Zero flux	Inlet, zero slip
2	Ground Electrode	No slip wall	Ground	Stick condition
3	Gas Outlet	Pressure	Zero flux	Outlet
4	Emitting Electrode	Slip wall	Electric potential + charge density	Bounce condition

Fig. 2: 2D-axissymmetric configuration and boundary conditions

Results/Analytical Verification

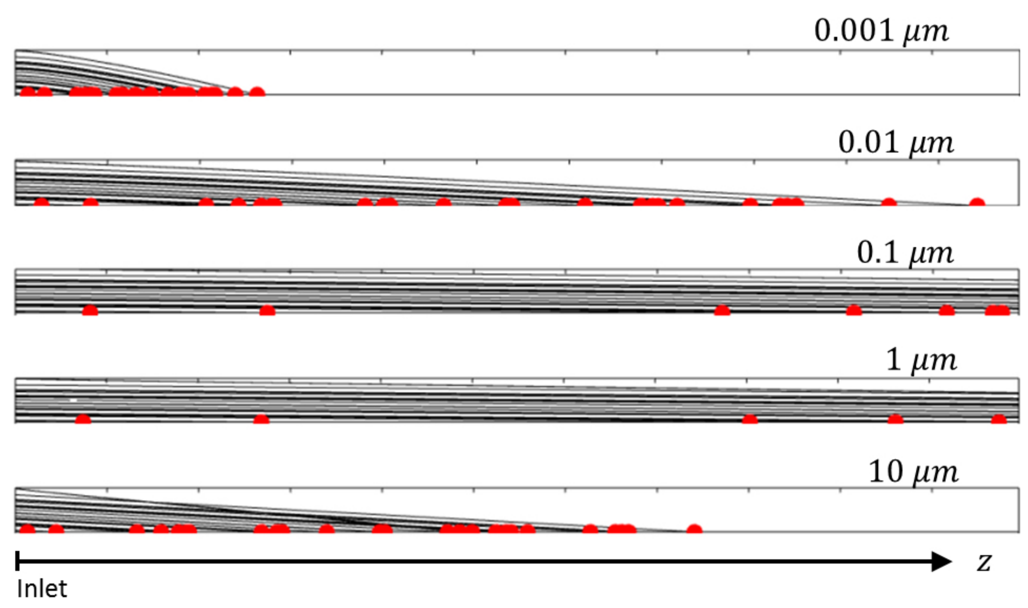


Fig. 3: Particle trajectories for five chosen particle sizes. The smallest 0.001μm particles are completely desposited right away due to the weak influence of drag. To the other extreme, the largest particles are deposited fully due to their substantial charging ability. The 0.01μm particles manage to deposit likewise, despite the increased drag. Inbetween a complete deposition is not achieved, as electric force and drag force balance each other out.

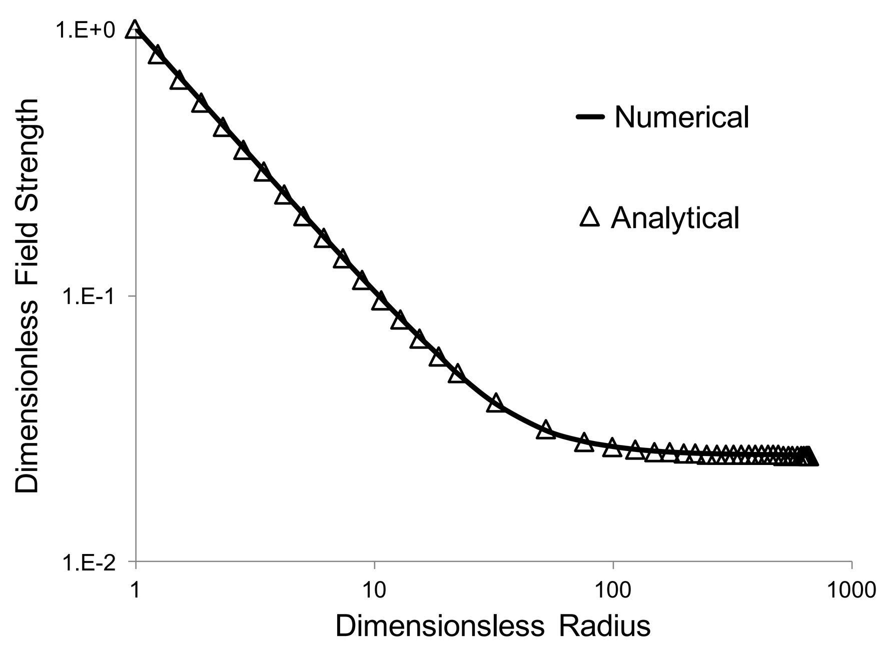


Fig. 4: The numerical and analytical result for the electric field strength are identical.

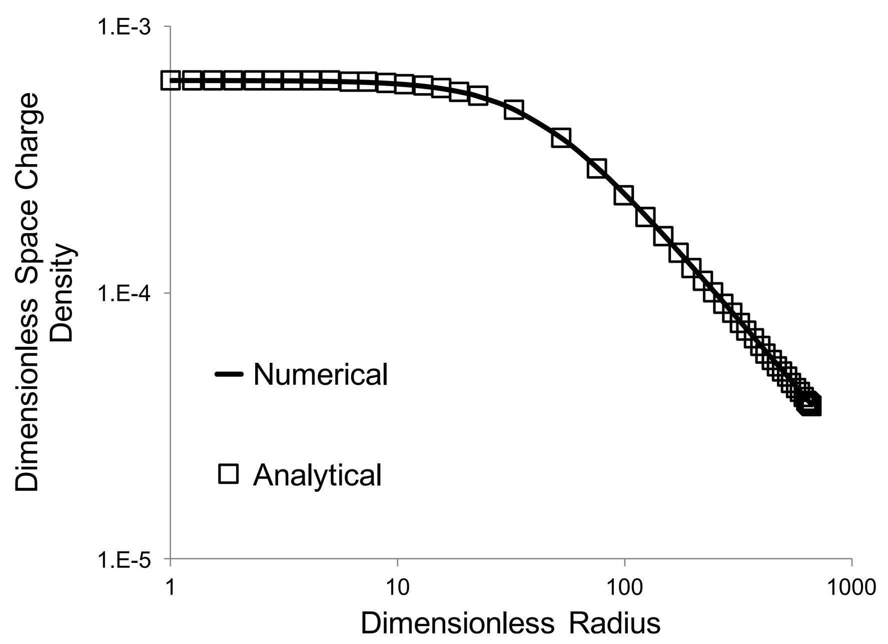


Fig. 5: The results for the space charge density also could be verified analytically.

References

[1] Poppner, Marc et al. (2005): *Electric Field coupled with ion space charge. Part 1+ 2. Journal of Electrostatics.* Volume 63. p. 775-787. Amsterdam: Elsevier

[2] Hinds, W. (1999): *Aerosol technology - properties, behavior, and measurements of airborne particles.* 2nd edition. New York: John Wiley & Sons.

Experimental Validation

The model has been adapted and compared to existing experimental data.

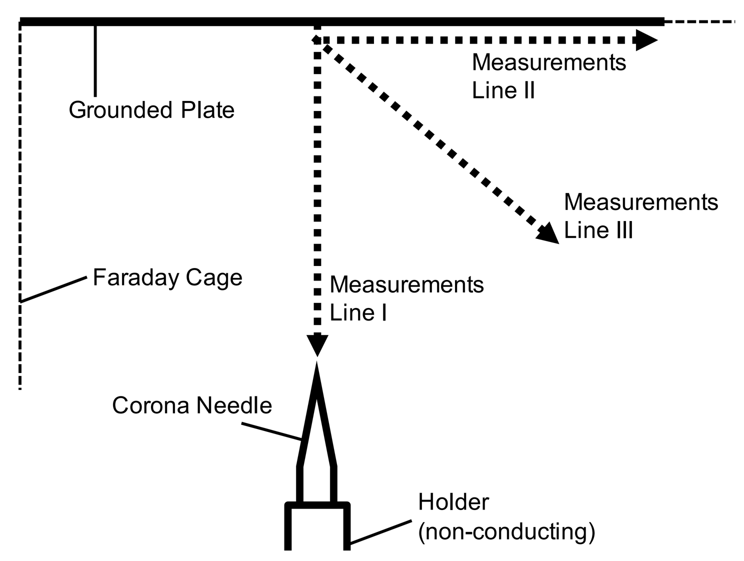


Fig. 6: Measurement setup as carried out by Poppner *et al.* [1] to measure electric quantities in a emitting Corona environment along the drawn lines.

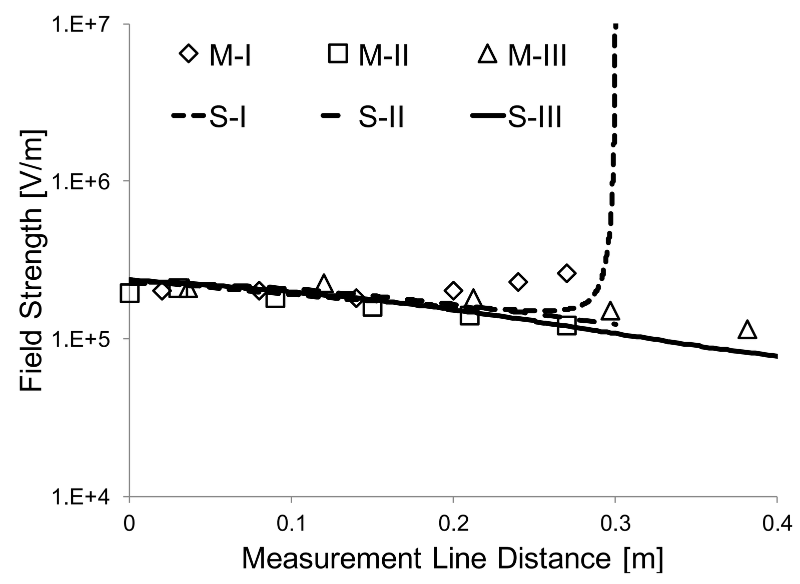


Fig. 7: Comparison of simulation results (S) and measurements (M) for the electric field. Towards the electrode the measurement device cannot handle the high gradients.

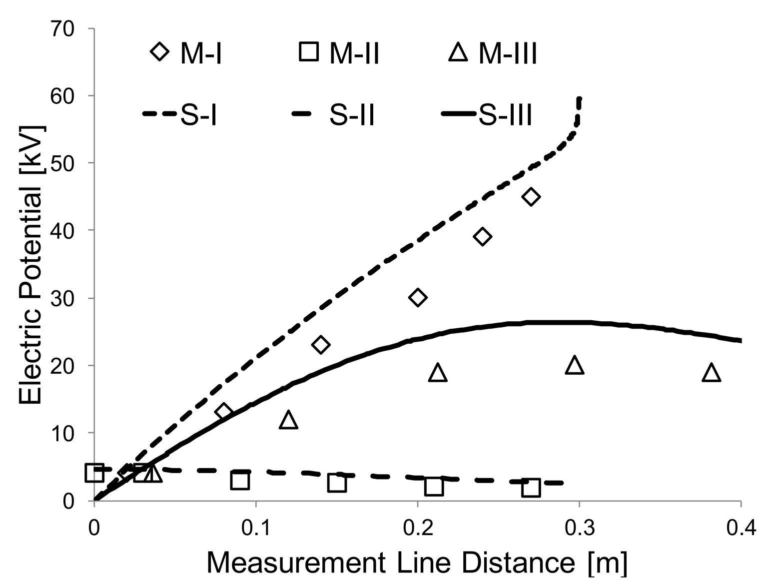


Fig. 8: As integral quantity, the experimental data for the electric potential matches the numerical results closer.

Discussion

- By means of a wire-tube test case the proposed model has been successfully verified. It performs both stable and accurate.
- The results for particle deposition efficiency match the expectations according to Deutsch-Anderson relation (Fig. 9)

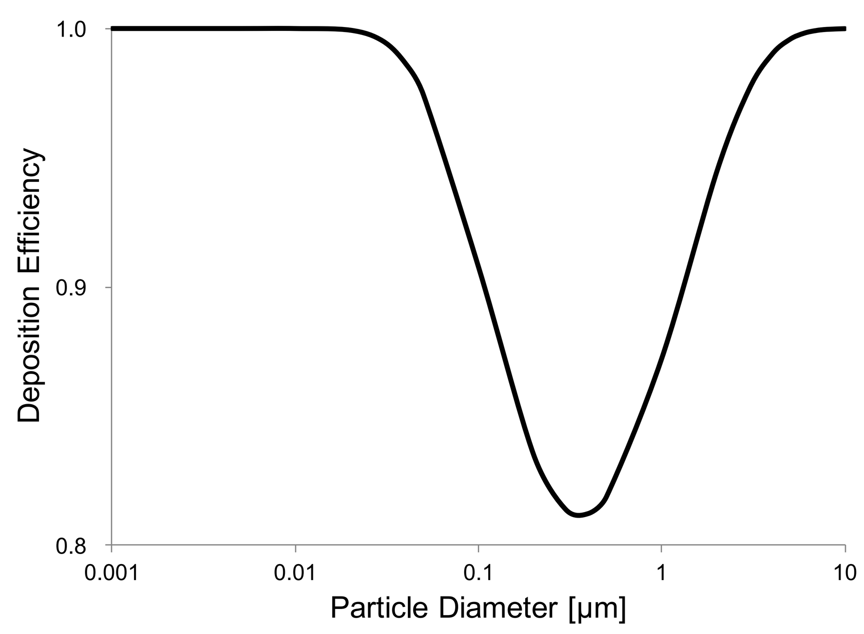


Fig. 9: Deutsch-Anderson relation between deposition efficiency and particle size [2]

- The proposed model can seamlessly be adapted to parent applications which involve particle charging and acceleration.