„Investigation of a Piezoelectric Plasma Generator as a Charging Source for Aerosols”

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The CeraPlas™

- TDK developed low-cost piezoelectric cold plasma generator “CeraPlas”

Properties of the CeraPlas

- cold plasma generation with ion densities up to 2E13 ions/m³ for each polarity
- no special plasma generating electrode required
- no high-voltage plugs or cables needed
- low plasma temperature (< 50 °C)
- dimensions [mm]: 45 x 4 x 2.8 or 70 x 6 x 2.8

Applications

- surface activation
- ozone generation
- sterilization of medical equipment
- wound disinfection

Low input voltage (12V) High output voltage (10 – 15 kV)
The CeraPlas™
Can the CeraPlas™ act as ion source for bipolar aerosol charging?

Why is this a relevant question?

- Established neutralizers for aerosol size distribution measurements (radioactive, x-ray, Corona) suffer from some drawbacks
  - ineffective for highly charged or small particles and high particle concentrations
  - permission needed for laboratory usage → expensive
  - high voltage generation (Corona)

- CeraPlas benefits
  - high ion concentrations at low power
  - safe operation
  - low-cost
  - small form factor (comparable to lambda sensor)
Can the CeraPlas™ act as ion source for aerosol charging?

How can this question be answered?

- determination of charging parameters based on ion density measurements
- measurement of charge distributions
- tuning of charge distributions to be comparable to reference (Wiedensohler approximation[1])
- Scanning Mobility Particle Sizer (SMPS) spectra: DBD-charger vs. $^{85}$Kr charger

Our strategy

- Quick-and-dirty SMPS measurements
  - replace neutralizer by CeraPlas
  - can aerosol particles principally be charged by the CeraPlas?
- Charge distribution measurements
  - charge distribution comparison to reference ($^{85}$Kr, Wiedensohler)?
- Determination of charging parameters
  - measurement of ion densities
  - $N_i t$ product $\rightarrow$ estimation of steady-state charge distribution
- Tuning of charge distribution
  - tuning of operating parameters to become comparable to reference

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**Ozone-free post-DBD aerosol bipolar diffusion charger: Evaluation as neutralizer for SMPS size distribution measurements**

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Strategy

- Quick-and-dirty SMPS measurements
- Charge distribution measurements
- Determination of charging parameters
- Tuning of charge distribution
Quick-and-dirty SMPS Measurements

- CeraPlas was mounted inside a pipe
- A charging chamber was designed for mixing of ions and particles to avoid particle contamination of the device
- With an electrostatic precipitator the charging effect of the CeraPlas was compared to a TSI 3088 x-ray source

Experimental Setup

- Mixing chamber (charging zone)
- Particle inlet
- Ion inlet
- Outlet

CeraPlas™

N₂

ATM220
NaCl

DT 570

HEPA

HEPA

HEPA

HEPA

Mixing Chamber

CeraPlas Package

CeraPlas

Pump

MFM

HEPA

ESP

HEPA

LDMA 3081

CPC3775

x-ray 3088
First Results

- No particles “visible” without charging source (#1, #4)
- Charging of neutral particles with CeraPlas (#2)
- Charging of neutral particles with TSI 3088 x-ray neutralizer (#5)
- Particle emissions from device (tested with HEPA filter): no particle contamination from CeraPlas (#3)

Experimental Setup

→ Basically it is possible to charge particles using the CeraPlas
Strategy

- Quick-and-dirty SMPS measurements
- Charge distribution measurements
- Determination of charging parameters
- Tuning of charge distribution
Results: Charge Distributions CeraPlas vs. Reference

- negative charging fractions show correct trend
- big deviations for positive charging fractions
- for bigger particle sizes results fits better to reference
  → steady state conditions??

→ investigation of charging parameters!!
Strategy

- Quick-and-dirty SMPS measurements
- Charge distribution measurements
- Determination of charging parameters
- Tuning of charge distribution
Determination of Charging Parameters

- **Ion densities measurements**
  - important to characterize CeraPlas
  - input parameter for calculation of \( N_i t \) product
  - determination of \( N_i / N_p \) which should be > 10 \[3\]

- **\( N_i t \) product**
  - product of ion density times the residence time of particles in that ion atmosphere
  - a value of 6E12 sm\(^{-3}\) necessary to achieve steady state charge distribution which is independent from aerosol concentration and initial charge \[2\]
  - high \( N_i t \) product important for reliability and reproducibility of SMPS measurements

- **Methods**
  - measurement of **inlet ion concentrations** with Ionometer IM806V2
    \[
    N_i^+ = (3.48E6 \pm 0.05E6) \text{ cm}^{-3} \\
    N_i^- = (3.15E6 \pm 0.08E6) \text{ cm}^{-3}
    \]
  - calculation of \( N_i t \) product with multiphysical simulation

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Ni\textsubscript{t} Product

- ...is the product of ion density times the residence time of particles in that ion atmosphere
- ...is an important charging parameter (indicator of steady state charge distribution)
- normally the Ni\textsubscript{t} product is determined via
  - measurement of ion density in charging area
  - calculation of residence time from flow rate assuming plug flow
    \(\rightarrow\) not very accurate
- Idea: determination via 3D model \(\rightarrow\) simulation of mixing chamber
**N_i t Product – Modelling of Mixing Chamber**

- **Determination of the N_i t product**
  - turbulent flow profile within mixing chamber
  - ion density profile: transport of positive/negative ion species
    \[
    \frac{\partial N_i^+}{\partial t} = \nabla (-D_{i^+} \nabla N_i^+) + u \cdot \nabla N_i^+ - \alpha N_i^+ N_i^- \\
    \frac{\partial N_i^-}{\partial t} = \nabla (-D_{i^-} \nabla N_i^-) + u \cdot \nabla N_i^- - \alpha N_i^+ N_i^- 
    \]
    $N_i^\pm$ ... pos./ neg. ion density
    $D_i^{\pm}$ ... ion diffusion coefficient (0.357E-5 m²/s, [4])
    $\alpha$ ... ion recombination coefficient (1.6E-12 m³/s [2])
  - “typical” particle trajectory: drag force acting on aerosol particle
  - calculation of N_i t product by integrating the ion density along particle trajectory
    \[
    N_i t = \int N_i [\tilde{q}_p(t)] dt
    \]

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![Flow velocity profile](image1)

Flow velocity profile (Q₁=0.3 lpm, Q₂=1 lpm)

![Ion density profile](image2)

Ion density profile ($N_i^{\pm, \text{inlet}} = 2E13$ m⁻³)

![Particle trajectory](image3)

Particle trajectory, released at midpoint of inlet cross section

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N_t Product – Results

- used parameters
  - Flow: Q_1 = 0.3 lpm, Q_2 = 1 lpm,
  - ion densities from measurement: \( N_{i^+} = 3.48 \times 10^{12} \text{ m}^{-3} \), \( N_i = 3.15 \times 10^{12} \text{ m}^{-3} \),
  - particle diameter \( d_p = 100 \text{ nm} \), number of released particles \( N_{p^{rel}} = 1000 \)

- \( N_t \) Product: \( N_{i^+}t = 3.95 \times 10^{11} \text{ s/m}^3 \), \( N_i t = 3.89 \times 10^{11} \text{ s/m}^3 \) \( \rightarrow N_t = 4 \times 10^{11} \text{ s/m}^3 \)

- Shortcomings of the model
  - diffusion coefficient of ions not known \( \rightarrow \) uncertainty
    (for model hydrated proton ionic clusters with \( D_{i^\pm} = 0.357 \times 10^{-5} \text{ m}^2/\text{s} \) were assumed)
  - ion recombination coefficient from literature
  - no consideration of other ion loss mechanisms (ion diffusion, space charge, etc.)

- Benefits of the model
  - flow consideration (usually plug flow is assumed)
  - ion density distribution considered

- Conclusions
  - new method of \( N_t \) product was introduced
  - \( N_t \) values of about \( 4 \times 10^{11} \text{ s/m}^3 \) is critically low
  - \( N_t \) product must be increased!!!
Strategy

- Quick-and-dirty SMPS measurements
- Charge distribution measurements
- Determination of charging parameters

- Tuning of charge distribution → t.b.d.
Summary and Outlook

- Bipolar aerosol particle charging is principally possible with CeraPlas
- Measured charge distributions show strong deviations from reference results
- Method for calculation of $N_i \cdot t$ product was introduced
- Charging conditions ($N_i \cdot t$ product) need to be enhanced

Next steps:

- Increase $N_i \cdot t$ product
  - increase residence time $t \rightarrow$ flow / geometry optimization
  - increase ion density $N_i \rightarrow$ power / positioning of CeraPlas
- Detailed investigation of charge distribution
  - steady-state conditions: is it possible to be comparable to reference?
  - impact of particle concentration / size
Thank you for your attention!!

Questions???????