ELECTRO-COLLECTION DANS UN CHARGEUR A DECHARGE COURONNE : CONSEQUENCES SUR LA CHARGE ET LA PENETRATION

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TITLE

Electro-collection in a direct corona charger: consequences on charge level and penetration

RESUME

Cette étude se focalise sur les conséquences de la collection électrostatique des particules sur les électrodes d'un chargeur pointe-cylindre développé pour la mesure de concentration massique des particules inférieures à 2,5 µm (PM2.5). L'objectif est de corréler la masse déposée dans le chargeur aux modifications du courant de décharge électrique et des conditions de charge des aérosols (répartition spatiales des ions et du champ électrostatique). Les résultats montrent que pour des particules liquides d'huile le chargeur doit être en position verticale pour éviter la déstabilisation des conditions de charge. Pour des particules solides de NaCL une masse déposée de 10 mg induit une réduction de 10 % du courant de décharge et des niveaux de charge en sortie du chargeur ainsi qu'une augmentation de la pénétration des particules. Ces résultats préliminaires permettent de définir des recommandations en termes de stabilité du chargeur et de définir un indicateur pour imposer le nettoyage du chargeur.

ABSTRACT

This study is focussed on the consequence of the electro-collection of particles on the electrodes of a point-to-cylinder aerosol charger designed to monitor the mass concentration of particulate matter below 2.5 µm (PM 2.5).The main objective is to establish the correlation between the deposited mass in the charger and the modification of the discharge current and the charging conditions (spatial distributions of ion and electric field). Experimental results show that with DEHS particles, the charger should be operated in a vertical position to avoid destabilization of the charging conditions. For solid NaCl particles, a deposited mass of 10 mg induces a reduction of 10% of the discharge current and of the mean charge per particle as well as a reduction of the penetration of the particles. These preliminary results allows us to define operating conditions to limit the effects of the aerosol losses on the performances of the charger and to define a condition to define when the charger needs to be cleaned.

MOTS-CLÉS : charge unipolaire, décharge couronne, électro-collection, métrologie / **KEYWORDS:** unipolar charging, corona discharge, electro-collection, aerosol measurement

1. INTRODUCTION

Electrical techniques are widely used in aerosol properties measurements (Olfert and Collings, 2005, Intra et al., 2013, Cao et al., 2017). Corona discharges are a simple way to produce the ions required to charge the particle. The unipolar corona chargers can be divided into two main kinds; the direct chargers and the post-discharge chargers depending on whether the aerosol is injected in the discharge gap or in post-discharge (Alonso & Huang, 2015; Jidenko et al., 2020). Direct chargers leads to a higher number of charge per particle related to higher ion concentration and field charging mechanism. The number of charge on particle can be predicted by theories or models (Pauthenier & Moreau-Hanot, 1932; Bricard, 1962; Boisdron & Brock, 1970).

However, for direct chargers, the deposition of particles on the electrodes due to diffusion and inertial effects but mainly to electro-deposition can lead to unstable charging conditions. The contamination of the electrodes can result in a modification of the curvature of the electrode, a decrease in the distance between two electrodes and change the voltage drop. Ultimately, the performances of the charger are modified by the above situations. For the corona discharge, numerous literature indicated the deposition of particles on the collection electrode reduces the discharge current (I_d) (Unger et al., 2004). Moreover, once the electric potential of the particle layer overcomes the threshold electric field (i.e. back corona occurs), the I_d increase. The back corona, in general, occurs when the resistivity of the particle layer above 10^{11} Ω-cm. Besides the experimental data, the deposition effect on discharge can also be predicted by theories that focus on the calculation of voltage drop resulted from the particulate layer.

This study aims to investigate the effect of the electro-deposition of the particle in a corona charger and the consequences on aerosol charging. A direct corona charger was designed, built, and tested. Solid and the liquid particles were deposited in the charger. The discussions are focused on the relation of the loading amount, charging condition, and the performance of the charger (mean charge per particle and particle penetration).

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2. MATERIAL AND METHOD

2.1. Charger geometry

Fig 2.1 shows the schematic diagram of the direct needle-to-cylinder charger prototype. The space inside the charger can be divided into a charging zone and an ion-trap zone. In the charging zone, a Platinum (Pt) wire (outer diameter: 100 μm; length: 6 mm) is used as the active electrode and is polarized with a high positive voltage to create ions. The ion density (N_i) in the charging zone can be controlled by varying V_{app}. An insulator piece of polyether ether ketone (PEEK), is used to hold the Pt wire and separate it from the ground electrode. The grounded electrode is a stainless steel cylindrical case of 36 mm in inner diameter and 70 mm in length.

Aerosol with a flow rate of 16.7 L/min is injected in the charger, and mix with the ions in the charging zone.

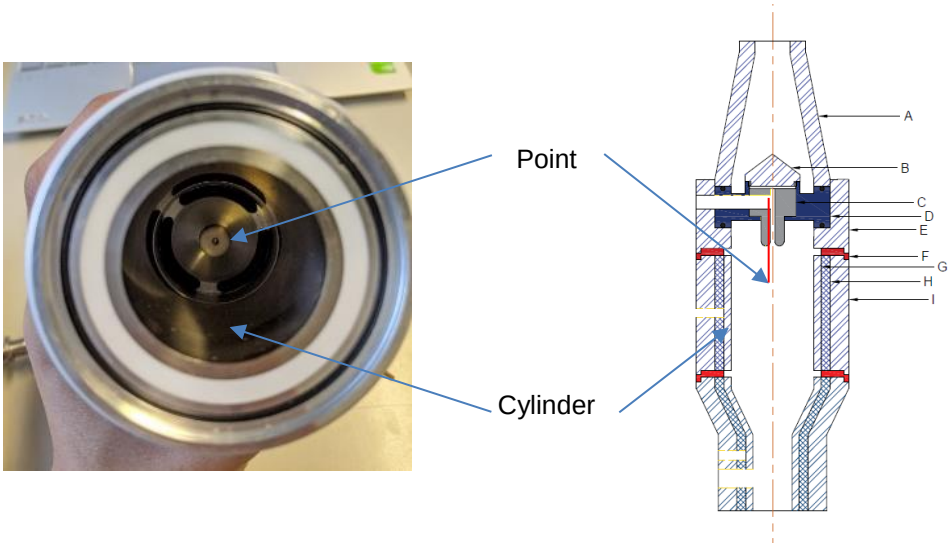

Figure 1. Schematic diagram and picture of the direct needle-to-cylinder charger.

An ion-trap collects all free ions downstream the charger (iron wire of 1 mm diameter and 15 mm length and a cylinder of 7 mm inner diameter). The residence times of the particles in the charging zone and the ion-trap zone are 0.15 s and 0.1 s, respectively.

2.2. Experimental setup

Fig 2 shows the experimental setup, which includes an aerosol generation system, a corona discharge monitoring system, and aerosol measurements. For corona discharge monitoring, the applied voltage V_{app} and the discharge current was measured with an oscilloscope connected to a high voltage single ended probe. The ion current collected in the ion trap I_{ion} was measured by an electrometer. Temperature is set between 20 to 25 °C, pressure between 990 to 1010 mbar, and relative humidity RH<10%.

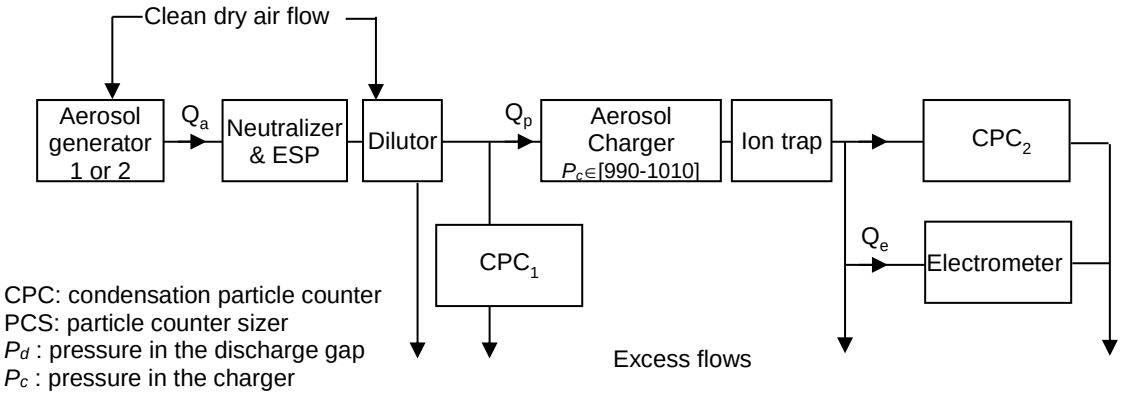

Figure 2. Flow diagram of the experimental setup

Two kinds of particles were used in this study to characterize the effect of aerosol electro-deposition on the performance of the charger. NaCl (electrical mobility. $D_{p,e}$=50 and 150 nm) particles were generated by a nebulizer (Model 3076, TSI Inc., St. Paul, MN). To measure the mean charge and the penetration the nebulizer is followed by a selection with a long DMA (Model 3081, TSI Inc.) to generate monodispersed particles. DEHS ($D_{p,e}$=700 nm) are produced by a Sinclair-Lamer generator.

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The instruments used to measure aerosol properties include a Condensation Particle Counters (CPC, model 3022A, TSI Inc.) and a Faraday-cage-Electrometer (FCE, model 3068A, TSI Inc.). The CPC was connected to the inlet/outlet of the charger to measure the particle concentration upstream ($N_{P,in}$)/downstream ($N_{P,out}$) the charger, and the penetration is calculated as: $\mathrm{P} = \frac{N_{P,out}}{N_{P,in}}$

where $N_{P,in}$ is the number concentration of particles upstream the charger and $N_{P,out}$ is the concentration downstream.

The current of charged particle is measured by a Faraday cup electrometer (FCE) downstream the corona charger. Then the mean charge per particle *n* is calculated as:

$$n = \frac{I_{FCE}}{eN_{P,out}Q_{FCE}}$$

Where I_{FCE} is the current measured by *FCE* (A); *e* is the elementary unit of charge (1.6×10^{-19} C); Q_{FCE} is the flow rate injected into the *FCE* (L/min).

To reduce the experiment time, all the loading processes have been carried out at 8 kV (with an initial discharge current I_d of 10 µA for aerosol concentration above few 10^5 cm^{-3}. It should be noted that the deposited patterns are different under various V_{app}, even for the same deposited mass. During the loading process, V_{app} is fixed while the I_d is a function of the deposited mass. The corona discharge and aerosol charging were measured at the loading time of 0, 1, 2, and 3 hours. The performance of aerosol charging is evaluated at constant I_d conditions (I_d =1.9, 6 and 10 µA) for monodispersed aerosol with concentration below 10^4 cm^{-3} to limit the effect of aerosol space charge on the discharge.

For solid and liquid particles, the deposited masses are calculated from aerosol penetration and particle size distribution. For solid and liquid particle, the deposited mass is weighted after each experiment, the results agree within 20% with the calculated ones.

3. RESULTS AND DISCUSSION

The effect of the collection of insulating materials is first reported for liquid particles (DEHS) with a special focus on the position of the charger (vertical or horizontal) and then for solid particles (NaCl).

3.1. Liquid aerosol (DEHS)

When the charger is operated horizontal, the evolution of the charged aerosol current measured downstream the charger is constant for 20 minutes (cf. Figure 3). As soon as the deposited mass reaches 1.8 mg +/- 2 mg some peaks of current are measured. The frequencies of the peaks increases with the deposited mass of liquid.

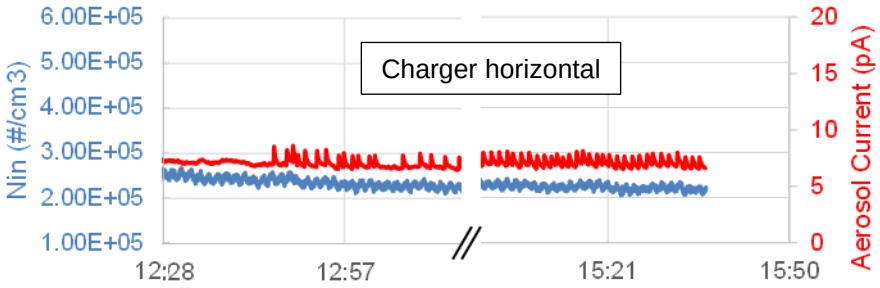

Figure 3. Temporal evolutions of inlet aerosol concentration (blue) and outlet charged aerosol current for DEHS particles of 700 nm at 2.3 10^5 cm^{-3} with I_d = 2 µA

At the beginning of the experiments, the discharge current is constant. For each burst of charged particle, the discharge current also present a peak. The most probable hypothesis is the formation of a liquid film at the bottom of the charger leading to small electrosprays. At least, these peaks are not observed when the charger is operated vertical. Moreover, the discharge and post-discharge ion currents as well as the mean charge per particle and the penetration remains constant for at least 3 hours.

As a conclusion, the charger should be operated in a vertical position to limit the effect of insulating liquid particles.

3.2. Solid aerosol (NaCl)

The discharge current decreases with the deposition of NaCl particle in the charger, meanwhile the post-discharge current (collected in the ion trap) increases (cf. Figure 4). The ion current is more affected than the discharge current and could thus be used as a parameter to define when the charger needs to be cleaned.

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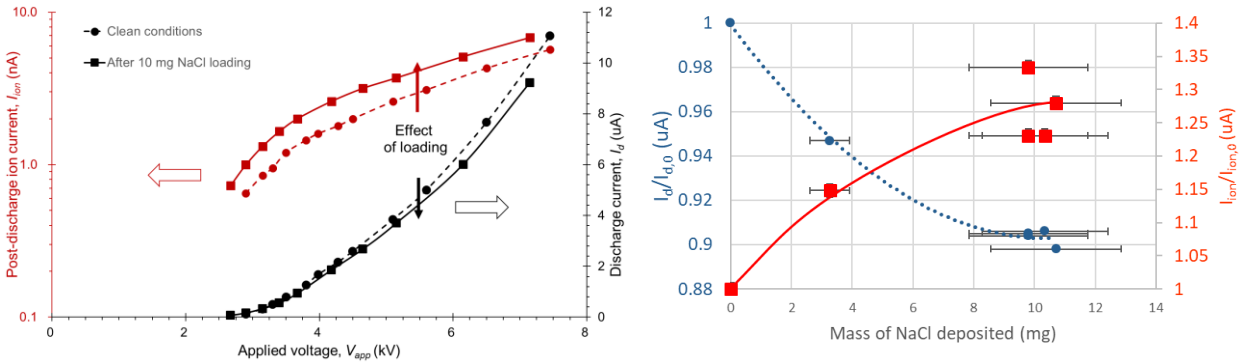

Figure 4. (a) $I_d(V_{app})$ curve and post-discharge ion current I_{ion} for a clean charger and after 10 mg of NaCl deposited in the charger (b) Evolution of the discharge and post-discharge ion currents as a function of the deposited mass of NaCl

These results were expected and confirm the formation of a salt layer that collect some ion with a surface potential that modify the electric field and the ion density profiles in the chargers. With particle loading, the mean charge per particle decreases while the penetration of particle increases (cf. Figure 5).

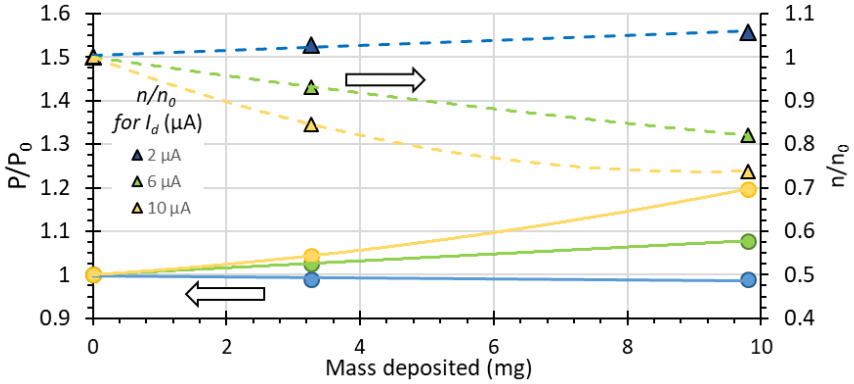

Figure 5. Evolutions of the penetration and the mean charge per 150 nm particle as a function of the deposited mass of NaCl for a discharge current of 2, 6 and 10 µA.

To conclude, the electro-collection of insulating solid and liquid particle in a point-to-cylinder charger has been investigated. The charger should be operated vertical to avoid the destabilisation of the discharge current induced by the liquid film on the electrodes. For solid particle, a low discharge current enables the charger to operate for a long time (about one week for aerosol concentration of a few 10^4 cm^{-3}) due to limited electro-collection and to limited evolutions of the mean charge per particle and penetration with the deposited mass. At last, a condition on the post-discharge ion current could be used to define when the charger requires to be cleaned.

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