Modifications to the bipolar charging theory for spherical particles

J.L. de La Verpillière[1], J.J. Swanson[1], A.M. Boies[1]

[1]Department of Engineering, University of Cambridge, Cambridge, UK, CB2 1PZ
Keywords: electrical mobility, Fuchs charging theory, neutraliser, unsteady state.
Presenting author email: jean.delaverpilliere@student.ecp.fr

In many cases, measurement of particle size and concentration depends on the knowledge of the distribution of charges they have acquired, either naturally or from a neutraliser. Since the use of radioactive materials such as ^{85}Kr is often a constraining factor in the lab, alternative commercial charging devices, relying on soft X-ray or AC corona discharge for ionization, have recently been developed. As shown on Fig. 1, it has been previously experimentally demonstrated that such variations in neutralization techniques lead to different charging characteristics (Swanson et al., 2012). Direct measurement showed that different neutralisers produce ions with different electrical mobility distributions, but the standard Fuchs charging theory failed to explain the observed charge distribution discrepancies between the neutralisers, even when the known mobility was used as an input.

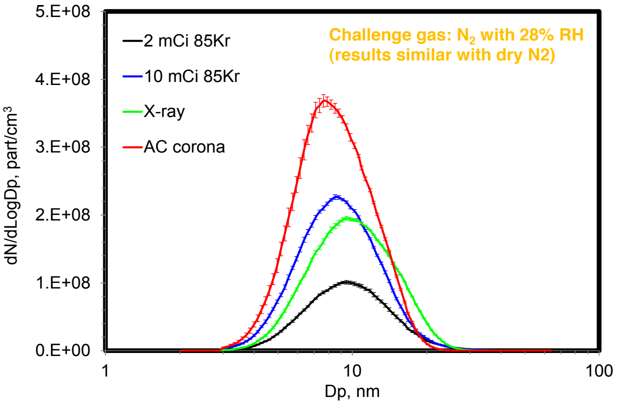

Figure 1. Inverted size distributions measured with an SMPS using 4 different neutralisers. Source particles are spherical silver particles.

In Fuchs theory, it is assumed that spherical particles interact with a cloud of bipolar ions of known and uniform characteristics in terms of mass, electrical mobility, and ratio of positive to negative ions (Fuchs, 1963). This steady state assumption is a useful closure relation that enables a rapid calculation of the charging state. Subsequent to this model, others such as Alonso and Alguacil (2003) have developed the theory to account for non-steady effects. They showed that in the case of a cylindrical charger with an alpha particles source on the wall, the unsteady effects of diffusion losses tend to make the extrinsic efficiency of the neutraliser smaller than its experimentally measured charging probability. On the other hand, the attraction between a given ion and a given particle is described by the ion-aerosol attachment coefficients. So far the effect of electrical mobility on the derivation of the attachment coefficients has only been investigated by varying the mean ion mobility in the model. The objective of this work is to investigate two modifications to the existing bipolar charging theory in order to improve the understanding of the mechanisms responsible for charging inside three commercially available neutralisers.

The first modification is to consider that steady state is not reached within the neutraliser due to ions diffusion losses to the neutraliser wall, as a result, the ion properties are no longer considered uniform along the neutraliser. Transport equations for particles of each polarity and for ions are derived from charge conservation equations, and solved using a forward numerical method. Alonso and Alguacil's (2003) model is therefore extended to neutralisers of more complex geometries, relying on different ionizing sources (beta particles and soft X-rays). Multiple charging has also been implemented into the model.

The second modification is related to the derivation of the ion-aerosol attachment coefficients. It is well known that ions of a wide mobility range are generated within a neutraliser. Ion mobility was therefore not treated as a discrete parameter, but as a stochastic variable. It was then possible to identify which kinds of ions actually control the charging process. Calculated results show that ions with a very high mobility generally have a higher overall charging activity than ions with a smaller mobility, despite the latter having a higher concentration.

Results of the numerical simulations are compared to the experimental trends to determine whether the physical explanations used to justify the theoretical modifications actually reduce the discrepancies observed between neutralisers. Our numerical simulations confirm that in all cases, unsteady effects are more important for very small particles, which has been observed experimentally. Ion electrical mobility has a significant impact on the ion-aerosol attachment coefficients and therefore influences the final particle charge distribution.

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