Re-creation of aerosol charge state found near HV power lines using a high voltage corona charger

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Abstract. Corona ionisation from AC HV power lines (HVPL) can release ions into the environment, which have the potential to electrically charge pollutant aerosol in the atmosphere. It has been hypothesised that these charged particles have an enhanced probability of being deposited in human airways upon inhalation due to electrostatic attraction by image charge within the lung, with implications for human health. Carbonaceous aerosol particles from a Technegas generator were artificially charge-enhanced using a corona charger. Once generated, particles were passed through the charger, which was either on or off, and stored in a 15 litre conducting bag for ~20 minutes to observe size and charge distribution changes over time. Charge states were estimated using two Sequential Mobility Particle Sizers measuring the size and mobility distributions. Charge-neutral particles were measured 7 times and positive particles 9 times, the average charge-neutral value of $x$ was 1.00 (sd = 0.06) while the average positive value was 4.60 (0.72). The system will be used to generate positive or charge neutral particles for delivery to human volunteers in an inhalation study to assess the impact of charge on ultrafine (size < 100 nm) particle deposition.

1. Introduction

Aerosols in the atmosphere can become electrically charged via collisions with air ions [1] but in most ambient environments remain in a ‘charge-neutralised’ state in which the number of positive and negatively charged particles is similar [2]. High Voltage Power Lines (HVPL) are a known producer of ions of one or both polarities, which are carried from the line into the atmosphere [3]. Downwind of HVPL, elevated levels of ions of one polarity over the other can cause an increase in aerosol charge state [4].

Particles can deposit in human airways by several mechanisms including diffusion, impaction, interception and sedimentation. Particle deposition is at its least efficient in the range of 200–300 nm [5], and it is at this point that electrical charge may cause enhanced deposition and hence cause an increase in particle deposition within the lung. Human volunteer studies [6] have shown enhanced lung deposition of highly-charged particles, mainly in the alveolar region, but no work has yet been undertaken at charge levels found downwind of HVPL nor for ultrafine (< 100 nm) sizes.

Increased deposition within the lung of charged ultrafine particles has been hypothesised as a possible causal link between HVPL and increased risk of childhood leukaemia [7; 8]. Theoretical modelling and experimental studies are required to test whether charge can increase deposition within the lung. Accurate re-creation of the charge states that could be found downwind of HVPL is essential for such studies.
2. Methods
Figure 1 shows the experimental set up used to verify the charge states of charged particles produced by a Technegas generator (Cyclomedica), a commonly used generator in nuclear medicine imaging studies, which produces carbonaceous particles with a log-normal size distribution of typical sizes 100-150 nm (geometric standard deviation of 1.5-1.9). Technegas particles are usually radio-labelled with Tc-99m, but here only de-ionised water or saline solution was used for safety reasons. It is also possible to remove the sodium from the pertechnetate radiolabel normally used in the Technegas generator [9]. This ensures no salt crystals are present in the particles, reducing mean particle size and minimising hygroscopic growth, both desirable properties in ultrafine particle inhalation studies.

Particles were charged using a custom built corona charger (Figure 2) based on the designs of Qi et al. [10] and Whitby [11]. The corona needle voltage, total flow rate and nitrogen flow rate (on each needle) can be altered to adjust performance. Through experiment with NaCl aerosol and Technegas particles, optimum parameters were found to be 10 lpm total flow, and 2 lpm nitrogen flow and +3.5 kV voltage for each needle. Corona current was stable at ~4 µA per needle, control of corona voltage alone was sufficient for repeatable charging as we observed a constant charge level over an hour's measurement and in repeated characterisation studies.

The vacuum pump and corona charger were connected to two solenoid valves that switched inlet and outlet from HEPA filters to the Technegas generator and a conducting bag. Nitrogen and aerosol flows were started, and where charging was required needles were energised to +3.5 kV and allowed to stabilise, before particles were generated. Following this, solenoid valves were switched for 50 s and particles were drawn from the generator by a vacuum pump through the corona charger (needles either energised to +3.5 kV, or grounded) into a 15 litre conducting bag. All tubing between instrumentation was electrically conducting to minimise particle losses.

Particle size and mobility distributions were measured using two Sequential Mobility Particle Sizers (SMPS+C, Grimm Aerosol), one with a neutraliser, over 5 'cycles' of 217 s, for total time ~20 minutes. This allows the charge distribution to be estimated [4]. The charge distribution can be represented by the average number of charges $n$ on particles of diameter $d$. At a constant charge temperature $T$ this can be described using a single parameter (the charge asymmetry ratio, $x$) as shown in equation 1, all other values being constant ($\varepsilon_0$ is the permittivity of free space, $k$ the Boltzmann constant and $e$ the charge on one electron) [12]. In total, charge-neutral Technegas particles were measured on 9 occasions, and positive particles on 7 occasions. Each measurement produced 5 size
distributions and 5 mobility distributions as the bag was emptied over 20 minutes, from which charge distributions were estimated.

\[ n = \frac{2\pi e_d k T}{e^2} \ln x \]  

(1)

3. Results

Table 1 shows results from the first SMPS+C scan of Technegas particles, passed through the corona charger on (positive) or off (charge-neutral) while Figure 3 shows the change in particle characteristics when holding in the bag for ~20 minutes. Mean (SD) of the charge asymmetry ratio, \( x \), for charge-neutral particles was 1.00 (0.05) implying an equal number of positive and negatively charged particles, and 4.60 (0.72) for positively charged particles. There is some run-to-run variability in the positive charge levels, with higher particle output from the Technegas generator leading to slightly lower charging. However, in all cases average particle charge is much higher than for charge-neutral particles. Particle count is lower for ‘positive’ compared to ‘charge-neutral’ particles, suggesting increased loss of particles during charging and bag transfer. Mean diameter (Figure 3b) is similar for positive and charge-neutral particles during the first scan, but charge-neutral particles subsequently grow by coagulation whereas for (unipolar) positive particles coagulation is reduced. Because particle size affects deposition efficiency considerably, for a robust comparison in volunteer studies, particles should be used within this ~200 s time frame.

| Charge-neutral | Charge Asymmetry Ratio (x) | Mean charges (100 nm) | GMD (nm) | GSD (nm) | Particle Count (cm\(^{-3}\)) | Positive | Charge Asymmetry Ratio (x) | Mean charges (100 nm) | GMD (nm) | GSD (nm) | Particle Count (cm\(^{-3}\)) |
|----------------|-----------------------------|-----------------------|---------|---------|-----------------------------|--------|-----------------------------|-----------------------|---------|---------|-----------------------------|
| 0.935          | -0.06                       | 96.55                 | 1.64    | 1472000 |                              | 4.522  | 1.32                        | 110.19                | 1.69    | 1062000 |
| 0.986          | -0.01                       | 102.59                | 1.68    | 1466000 |                              | 4.640  | 1.35                        | 110.63                | 1.71    | 1023000 |
| 0.992          | -0.01                       | 132.54                | 1.71    | 1676000 |                              | 5.178  | 1.44                        | 109.20                | 1.69    | 952000  |
| 1.094          | 0.08                        | 96.23                 | 1.61    | 1814000 |                              | 5.085  | 1.43                        | 115.31                | 1.68    | 975000  |
| 1.017          | 0.01                        | 111.73                | 1.64    | 1722000 |                              | 4.386  | 1.30                        | 138.56                | 1.69    | 1025000 |
| 1.028          | 0.02                        | 113.09                | 1.65    | 1905000 |                              | 5.918  | 1.56                        | 97.07                 | 1.65    | 923000  |
| 0.943          | -0.05                       | 135.45                | 1.67    | 1423000 |                              | 4.067  | 1.23                        | 123.70                | 1.65    | 1150000 |
|                |                             |                       |         |         |                              | 4.112  | 1.24                        | 113.91                | 1.69    | 1190000 |
|                |                             |                       |         |         |                              | 3.466  | 1.09                        | 131.84                | 1.66    | 1085000 |

4. Discussion

A charge asymmetry ratio of \( x = 1.71 \), which implies an average charge per 100 nm particle of 0.47, was observed for particles at a HVPL known to produce a high concentration of ions [4]. Particle charge states in this study are higher than this value, but considerably lower than those measured in the output of metered dose inhalers [13], thus we cannot extrapolate expected charge-related effects to these types of medical devices. Particles produced in this study thus represent an extreme example of what may be found near to HVPL and would therefore provide an upper limit on the possible enhanced ultrafine particulate pollution dose due to HVPL charging effects in real-world conditions.

The corona charger is being used in a human volunteer study in which charged particle deposition in human airways is being investigated. Charged and neutral particle deposition will be measured using particle counters and gamma scintigraphy. As the level of charge exhibited on the particles in this study is slightly higher than that found near HVPL, any observed increase in deposition in the proposed study is likely to be of higher magnitude than that found in populations living near HVPL.
Figure 3. a) Mean and standard deviation of particle number concentration; b) geometric mean diameter; and c) the average number of charges on 100 nm particles on charge-neutral and positively charged particles during holding in the bag for 20 minutes (6 scans). d) Size distributions for charged and charge-neutral particles during the first (~3 minutes after bag filling) and fifth (~16 minutes after bag filling) SMPS+C scans

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