Measurement of Unipolar Charged Aerosol Particles Using a Long Electrical Mobility Spectrometer

Yawooti A1, Intra P2,* and Tippayawong N1

1 Department of Mechanical Engineering, Chiang Mai University, Chiang Mai, Thailand 50200
2 College of Integrated Science and Technology, Rajamangala University of Technology Lanna, Chiang Mai, Thailand 50300

*Corresponding Author: Tel: (665) 3921444 Ext. 1012, Fax: (665) 3213183,
E-mail: panich_intra@yahoo.com

Abstract

In this work, a long electrical mobility spectrometer (EMS) was developed for measuring the unipolar charge of aerosol particles. The long EMS consists of three main parts: a particle charger, a long multi-channel size classifier column, and a multi-channel electrometer. Particle charging is carried out by exposing an aerosol sample to a cloud of unipolar corona ions inside the corona-needle charger, and then charged via ion to particle collisions. The charged aerosol passes into the multi-channel size classifier column, configured as coaxially cylindrical electrodes. A DC high voltage is applied to the inner electrode, while the outer electrode is grounded. There are two separate streams, aerosol and sheath air flows. The charged aerosols enter the size classifier column. A high electric field formed between the electrodes makes the particles deflected radially outward and particles having specific mobility are collected on electrically isolated electrometer rings, positioned at the inner surface of the outer electrode. A multi-channel electrometer connected to these electrometer rings measures signal currents corresponding to the unipolar charge of aerosol particles of a given mobility which is related to the particle size. The performance of this long EMS was evaluated using polydispersed, carbonaceous aerosol particles generated by a diffusion flame, combustion aerosol generator (CAG). Preliminary test results showed that the long EMS performed well and was a valuable tool available for measuring unipolar charge of aerosol particles.

Keywords: aerosol, particle, electrostatic charge, electrical mobility, spectrometer.

1. Introduction

The one of the most important parameters governing behavior of aerosol particles is the electric charge. Specific electric charge on aerosol particles have important role in the aerosol science studies due to electrostatic effects in powder production, handling, transport and sampling and also on deposition of respirable particles in the human respiratory tract [1]. The beneficial effect of particle charge is being used
successfully in many industrial applications, such as electrostatic painting and printing, crop spraying, gas cleaning, and in many other fields [2]. Information on the electrostatic charge of the particles is the paramount importance for the adequate treatment of the process. Therefore, it is desirable to characterize and measure the level of these charged aerosol particles in order to better understand them.

A number of measurement methods of electrostatic charges in particles have been reviewed by Brown [3]. The most commonly and widely used technique is the electrostatic technique. Available instruments include the Faraday pail/chamber electrometer [4], differential mobility analyzer (DMA) [5], electrical aerosol analyzer (EAA) [6], electrical aerosol spectrometer (EAS) [7], bipolar charge aerosol classifier (BCAC) [8], and short electrical mobility spectrometer (EMS) [9]. These developed instruments are most suitable for site-specific, high resolution particle size and charge distributions.

Recently, we have been designed and developed a prototype of a long EMS for measuring unipolar charge and size of aerosol particles. It was therefore necessary to improve and investigate the classification and measurement performances of particle charges of the long EMS. Thus, this paper presents the results of the research work that was carried out in developing an instrument capable of measuring electrostatic charge levels of aerosol particles.

2. Description of the Long EMS

Figure 1 shows schematic diagram of the long EMS. It consists of a size selective inlet, a corona-needle charger, a multi-channel size classifier column, a multi-channel electrometer, a data processing system, a DC high voltage power supply, and flow control system. The aerosol sample first passed through the corona-needle charger. Particle charging is accomplished by exposing aerosol sample to the cloud of unipolar corona ions, and then charged via ion-particle collisions. The charged aerosol passes into the multi-channel size classifier column, configured as coaxially cylindrical electrodes. There are two separate streams which are aerosol and sheath air flows. The charged aerosols enter the multi-channel size classifier column close to the inner electrode by a continuous flow of air, surrounded by a sheath air flow. Because the inner electrode is kept at a positive voltage, the charged particles are then deflected outward radially according to the electrical mobility and they are collected on a series of electrically isolated electrometer rings along the outer wall of the classifier. Multi-channel electrometers connected to these electrometer rings measure currents corresponding to the electric charge of aerosol particles of a given mobility which is related to the particle size. Finally, signal currents are then recorded and processed by a data acquisition system with a time response of about 1 s. The particle charge, $q_p(d_p)$, as a function of particle diameter, $d_p$, can be calculated by the following equation

$$q_p(d_p) = \frac{3\mu d_p L \ln(r_2/r_1)}{2VL_i C_i(d_p)}$$

where $\mu$ is the air viscosity, $Q$ is the total flow rate through the size classifier column, $r_1$ is the inner electrode radius, $r_2$ is the outer electrode radius, $V$ is the applied inner electrode voltage, $L_i$ is the axial position between the aerosol entry location and the midpoint of the electrometer ring,
and $C_c$ is the Cunningham slip correction factor. The net charge of aerosol particles can be also calculated from the measured electrometer ring currents is given by

$$q_p = \frac{I_p}{Q_a}$$  \hspace{1cm} (2)

where $I_p$ is the measured signal current from the electrometer rings and $Q_a$ is the aerosol flow rate.

3. Experimental Setup and Procedures

3.1 Aerosol Generators

In this study, a combustion aerosol generator (CAG) was used to generate a polydisperse aerosol. Polydisperse aerosols were produced by a laminar diffusion burner with a kerosene fuel in the nominal “presooting” condition. Under normal conditions, the vast majority of soot generated by the flame would be oxidized, giving a very low particle number concentration. A quench-air flow across the tip of the diffusion flame assisted in the production of highly concentrated aerosols while it also served to carry the aerosol downstream of the combustion chamber. The quenched flame exhaust was then quickly diluted using a blower to provide an ultrafine carbonaceous aerosol.
Table 1 The operating conditions for the long EMS.

<table>
<thead>
<tr>
<th>Operating conditions</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle material</td>
<td>Carbon</td>
</tr>
<tr>
<td>Particle size range</td>
<td>10 – 1,000 nm</td>
</tr>
<tr>
<td>Inner electrode voltage</td>
<td>1.0 – 3.0 kV</td>
</tr>
<tr>
<td>Aerosol flow rate</td>
<td>3.0 L/min</td>
</tr>
<tr>
<td>Sheath air flow rate</td>
<td>25 L/min</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>0.85 bar</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>30°C</td>
</tr>
</tbody>
</table>

The number concentration and particle size distributions can be generated by varying the air and fuel flows in the combustion chamber, the level of the flame nozzle from the top of the chamber, and the quench air flow. The sample particles from the CAG were also characterized by the scanning electron microscope (SEM) and the energy dispersive spectroscopy (EDS) for morphology and chemical composition, respectively. The particle size distribution from the CAG was in the range between approximately 10 nm to several hundred nanometers.

3.2. Experimental System and Procedure

The complete experimental apparatus used in the measurement of the charged aerosol particle can be seen in Figure 2. The long EMS was operated at aerosol flow rate of 3.0 L/min, pre-filtered sheath air flow rate of 25.0 L/min, size classifier voltage between 1.0 kV and 3.0 kV, and operating pressure of 0.85 bar. Aerosol sampling was carried out using an isokinetic sampling system. The aerosol particles were first dried with the diffusion drier. Thus, any remaining water was removed. Due to the high particle concentration in the particle stream flow rate of the exhaust, before aerosol particles entering the long EMS, the particles were diluted and mixed with clean air, which had been filtered through a HEPA filter, in the mixing chamber. The operating condition for the long EMS is shown in Table 1.

4. Results and Discussion

Figures 3 – 5 show measurement of charge distribution on different electrometer rings. Three different operating conditions were experimentally studied in the effect of electric field
strength on the charge distribution measurements of the long EMS. Because of the electric field strength within the spectrometer is a function of applied inner electrode voltage. Therefore, the magnitude of the potential applied to the inner electrode was varied between 1.0 to 3.0 kV. As shown in these Figures, the net charge of the tested aerosol particles obtained from each electrometer rings is in the range from 0 to 2.9 x 10^{-6} C, corresponding to the measured electrometer ring currents is in the range from 0 to 145 x 10^{-12} A. It was also found from the results that when higher electric field is created within the size classifier column of the long EMS, more charged particles are precipitated and deposited on the first electrometer ring. This was expected because the electrical mobility of charged particles being collected at each electrometer ring was inversely proportional to the electric field strength. The inverse ratio of the inner electrode voltages should be equal to the shift in particle mobility due to the change in electric field strength.

5. Conclusions

Measurement of unipolar charged aerosol particles using a long EMS was introduced in this paper. The performance of this long EMS was evaluated using polydisperse carbonaceous aerosol particles generated by a diffusion flame, CAG. It was found that the net charge of the tested aerosol particles obtained from each electrometer rings is in the range from 0 to 2.9 x 10^{-6} C, corresponding to the measured electrometer ring currents is in the range from 0 to 145 x 10^{-12} A. It was also shown that the results of the preliminary experimental study indicate that the constructed instrument can be
successfully used for measuring unipolar charged aerosol particles.

6. Acknowledgement
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7. References