Assessment of Voltage Shift in Tandem DMAs by Brownian Particle Trajectory Simulation

M.Alonso[1], F.J. Alguacil[1], J.P. Santos[2] and V. Gómez[3]

[1]Centro Nacional de Investigaciones Metalúrgicas (CENIM-CSIC), Madrid, Spain
[2]Instituto de Física Aplicada (IFA-CSIC), Madrid, Spain
[3]Instituto de Nanociencia de Aragón (INA), Zaragoza, Spain
Keywords: Tandem DMA, voltage shift, Brownian particle trajectory
Presenting author email: malonso@cenim.csic.es

Past experimental works have shown that when two geometrically identical differential mobility analyzers operating under the same conditions are connected in series, in such a manner that the particles classified by the first unit are fed to the second one (tandem DMA), the peak voltage at which particles are classified in the second instrument may substantially differ from the fixed voltage applied to the first DMA.

Voltage shifts only appear when the aerosol particles have a very high mobility. When these particles are present at sufficiently large concentrations, the additional space-charge electric field created by the unipolarly charged particles migrating between the DMA electrodes may be of the same order of magnitude as the applied field, in which case, the simple Knutson-Whitby relationship between mobility and voltage ceases to be valid.

The voltage shift phenomenon may even arise when the aerosol concentration is not large. In this case, the strong Brownian motion of the particles leads to the appearance, in the classified aerosol stream, of particles with mobility outside the theoretical range. Figure 1 illustrates this point. Suppose that the actual mobility distribution of the original aerosol is given by the curve shown, and that the voltage applied to the first DMA is such that the theoretical peak mobility of the classified particles is Z_1. Clearly, there are no particles with such mobility within the aerosol population; however, due to diffusion broadening of the transfer function, some particles in the tail of the mobility distribution will appear in the classification stream. If these particles are subsequently fed to the second DMA and the voltage is scanned, it will be found that the peak voltage corresponds to a mobility $Z_2 < Z_1$, where, in contrast with Z_1, Z_2 is a "real" mobility, i.e. particles with that mobility do exist in the original aerosol.

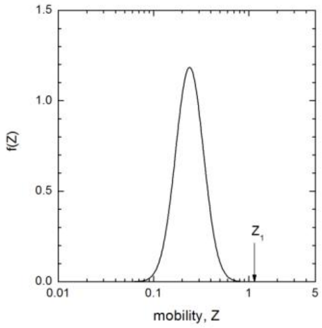

Figure 1. Particle Mobility distribution at DMA-1 inlet.

Numerical simulations of voltage shifts in tandem DMAs have been carried out, based on the calculation of the trajectories of Brownian particles under the applied electric field. The simulation starts by considering a log-normal mobility distribution for the original aerosol, and calculating the corresponding mobility distribution of the classified aerosol when a fixed voltage V_1 is applied to DMA-1 (the mobility Z_1 corresponding to this voltage is calculated with the well-known Knutson-Whitby relation). The aerosol having the thus calculated distribution is then reclassified in DMA-2. The voltage applied to the second unit is scanned, and the program calculates the total number of particles classified at each voltage. From this distribution, the mean voltage $<V_2>$ is calculated and transformed into its corresponding mobility Z_2. The illustrative results shown in Figure 2 were obtained using TSI short-column DMAs (length = 11.11 cm) operated at Q_a/Q_c=2/20.

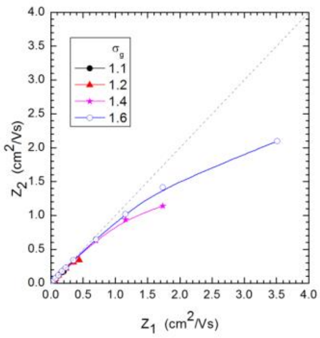

Figure 2. Peak mobility as measured from DMA-2 vs nominal mobility of particles classified by DMA-1. Log-normal particle size distribution at DMA-1 inlet, with D_{pg} = 5 nm, and σ_g as stated in the legend.

Quite large deviations between Z_1 and Z_2 can be observed in this example. It demonstrates the need to be cautious when using a DMA to withdraw very small particles, especially when their size falls within the tail of the distribution.

A final observation: In the example of Figure 1, we assumed that the aerosol mobility distribution was already known. In practice, this distribution is not known. We could then apply a certain voltage to DMA-1 and obtain a stream of particles with nominal mobility Z_1 (say, 3.5 cm^2/Vs), and we might believe that we are really producing particles with such a high mobility. According to Figure 2, the actual mobility of these particles is much smaller, about 2.1 cm^2/Vs, typical of negative air ions.