The accuracy of the DMA-APM mass measurement for sub-50 nm nanoparticles

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The tandem differential mobility analyser (DMA) and aerosol particle mass analyser (APM), denoted as the DMA-APM system, provides a high resolution of mass measurement for submicron particles (Ehara et al., 1996). However, the mass of sub-50 nm nanoparticles (NPs) measured by the system (m_{APM}) is always lower than the electrical-mobility-diameter-based reference mass, $m_{ref}(d_{mob})$, defined in equation (1), with the deviation up to 80 % (Tajima et al., 2011; 2013). The causes of the under-estimation are not clear, and are addressed in this study.

$$m_{ref}(d_{mob}) = \frac{1}{6}\pi(d_{mob})^3\rho_m \qquad (1)$$

The traceable size standards of polystyrene latex (PSL) and NanoSilica, and laboratory generated silver NPs, whose material densities (ρ_m) vary from 1 g/cm^3 to 10.49 g/cm^3, were applied to test the accuracy of the DMA-APM system (APM 3601, Kanomax Inc., Japan). The masses of the particles were measured with different λ_c and aerosol flow rates ($Q_{aerosol}$). The mass of agglomerated silver NPs without sintering was measured first ($m_{APM,NS}$). Then the particles were sintered at 700 ℃ to be spherical and the mass of the sintered particles was measured ($m_{APM,S}$). The $m_{APM,S}$ was compared to $m_{APM,NS}$ to study the effect of size and morphology of the particles on the mass measurement. Different slip correction factors were also examined to see if there is an effect on the mass measurement accuracy. Moreover, different reference masses were also discussed, including the reference masses calculated based on the Feret's and projected area diameters, respectively, which were determined with the transmission electron microscopy (TEM) and energy-dispersive X-ray spectroscopy (EDS).

It was found that λ_c, $Q_{aerosol}$ and the slip correction factor did not have significant contributions to the mass deviation, while the operational conditions at low $Q_{aerosol}$ (0.3 liter/min) and low λ_c (<0.2) were found to contribute to lower m_{APM} values due to weak classifying forces. The ratios of $m_{APM,S}$ to $m_{APM,NS}$ were 0.91±0.06 for 13 nm silver NPs sintered from 17 nm (d_{mob}, mobility diameter), 0.92±0.05 for 19 nm NPs from 30 nm (d_{mob}), and 0.99± 0.06 for 30 nm NPs from 50 nm (d_{mob}). The mass ratio was slightly reduced by the evaporation loss which could be due to the lower melting point of the silver nanoparticles with the diameter less than 20 nm (Shyjumon et al., 2006). Therefore, the mass ratio was expected to be closer to unity if the evaporation loss was taken into account, and it was a solid evidence that the APM mass measurement was not sensitive to both the morphology and size of the nanoparticles. In other words, the APM was accurate for small nanoparticles.

The study also observed that m_{APM} of the small nanoparticles was lower than the corresponding $m_{ref}(d_{mob})$, which agreed with data reported in literature. However, the deviation between the masses was reduced to less than ±10% when m_{APM} was compared to the projected-area-diameter-based referenced mass. Similar "improvement" was also observed when m_{APM} was compared to Feret's diameter-based reference mass. Therefore, it was concluded that the reference mass based on d_{mob} was the major factor that resulted in the under-estimation of m_{APM} as compared to $m_{ref}(d_{mob})$.

This study observes that the mass ratio of m_{APM} to $m_{ref}(d_{mob})$ is a function of d_{mob} independent to ρ_m of the particles (dash line in Figure 1). The data from previous literature (not shown) also follow the same trend. An empirical equation was proposed to correct for the error based on $m_{ref}(d_{mob})$. With this correction, the DMA-APM system is able to determine the mass of sub-50 nm nanoparticles with an error less than ±10% (solid symbols in Figure 1). The study improves the mass measurement accuracy of the DMA-APM for sub-50 nm nanoparticles.

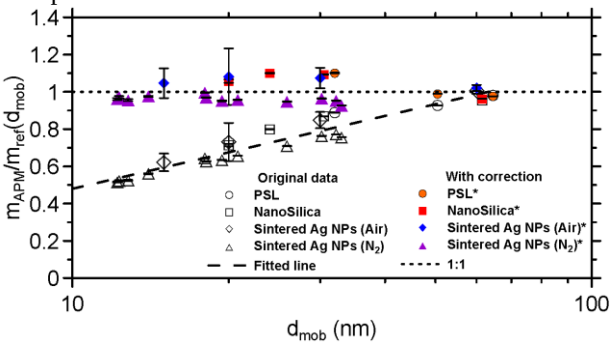

Figure 1. The ratio of m_{APM} to $m_{ref}(d_{mob})$ of different NPs

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