The effect of sampler design on nanoparticle sizing at high temperatures

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The properties (e.g. transport and optical properties) of aerosol nanoparticles formed at high temperature processes depend strongly on their composition, size and morphology and, thus, must be contolled closely to achieve the desired product performance, like mechanical stability. Online and real-time monitoring is a useful but intrusive method to study the growth of airborn particles. However, particle characteristics, measured by such methods, depend on the design and sampling of the dilution system (Burtscher, 2005) and often change through the sampling lines as subject to coagulation and/or fragmentation.

Here, the effect of different sampler designs (straight-tube and hole-in-a-tube of varying hole diameter and hole orientation), sampling and diluting hot, highly concentrated flame-made ZrO_2 nanoparticles, on their real-time characterization is investigated for the first time. Measurements by differential mobility analyzer (DMA) are compared to the Sauter mean primary particle diameter and geometric standard deviation calculated by counting transmission electron microscopy (STEM) images that are obtained by thermophoretic sampling at the flame centerline at 10 – 60 cm height above the burner (HAB). The geometric standard deviation, σ_g, of the mobility radius at high HAB and fuel-rich flame conditions approaches the self-preserving σ_g of about 1.75 as obtained by mesoscale simulations in the continuum regime (Goudeli et al., 2015).

The samplers' hole orientation affects the measured mobility diameters, especially for low HAB (10 – 40 cm) when hole-in-a-tube samplers are used. The straight-tube sampler results in smaller mobility diameters than the hole-in-a-tube ones for both fuel-rich and fuel-lean spray flames. Fig. 1 shows the mobility size distributions of ZrO_2 particles at HAB = 10 (thin lines) and 60 cm (thick lines) made by a fuel-lean spray flame, sampled and diluted by a hole-in-a-tube sampler with hole diameter of 4 mm (red lines) and a straight-tube sampler (green lines) in upstream orientation. The above distributions are compared to those obtained in the continuum regime by Discrete Element Modeling (DEM) method for spheres (broken line) and agglomerates (dotted line) showing that at high HAB particles attain the self-preserving size distribution (SPSD) by coagulation of agglomerates made by diffusion-limited cluster-cluster agglomeration. At low HAB (10 cm here), the mobility size distribution is narrower than the SPSD as particles have not attained their asymptotic agglomerate structure (D_f = 1.78).

Combined DMA and aerosol particle mass (APM) measurements are used to determine the mass-mobility exponent, D_{fm}, and average primary particle diameter by a power law correlation between particle mass and mobility diameter. The results are compared to the DEM-obtained D_{fm} and experimental measurements for ZrO_2 (Eggersdorfer *et al.*, 2012) and Cu nanoparticles (Stein *et al.*, 2013). The D_{fm} evolution from spherical to fractal-like aerosols is quantified by simple relationships in terms of the number of primary particles per agglomerate.

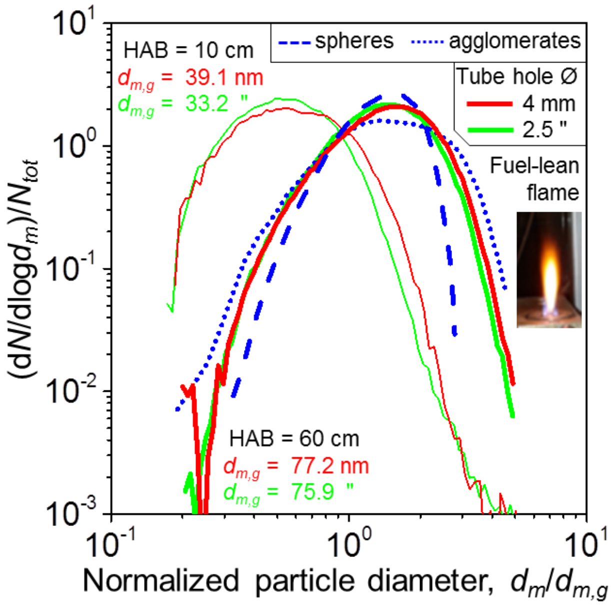

Figure 1. Mobility size distributions of ZrO_2 particles made by fuel-lean spray flame, sampled by hole-in-a-tube and straight-tube samplers (solid lines). The results are compared to DEM-obtained mobility radius-based SPSD of spheres (broken line) and agglomerates (dotted line) in the continuum regime.

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