Measurement of Airborne Carbon Nanofiber Structure Using a Tandem Mobility-Mass Analysis

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INTRODUCTION

The production of engineered nanostructured materials such as carbon nanotubes/nanofibers by using nanotechnology raises concern over the potential health hazards presented by such particles when manufacturing and handling them in the workplace (Shvedova *et al.*, 2005). Carbon nanotubes/nanofibers represent a unique class of engineered nanomaterial that may have applications in such fields as novel electronic devices and high strength materials (Subramoney, 1998; Applied Sciences, Inc). It is anticipated that size distribution, agglomerate state, shape, chemical composition, surface area and surface chemistry of these nanomaterials may be important physicochemical properties that could lead to adverse health effects (Oberdörster *et al.*, 2005).

A recent review of engineered nanomaterial toxicity tests emphasized the need to fully characterize airborne nanomaterials in the submicrometer size range (Oberdörster *et al.*, 2005). In this context, here, we applied a Differential Mobility Analyzer - Aerosol Particle Mass analyzer (DMA-APM) method (Park *et al.*, 2003) in real-time measurement of airborne carbon nanofiber structure.

METHODS

A schematic diagram of the experimental setup used is shown in Figure 1. As-produced Pyrograf® III carbon nanofiber material (Type PR-24, Grade LHT, Applied Sciences Inc.) was aerosolized using a vortex shaker-based generation system (Maynard *et al.*, 2004).

Carbon nanofibers aerosolized by a vortex shaker were introduced to a Po-210 neutralizer to provide a Boltzmann equilibrium charge distribution before entering the DMA. Then, the DMA-classified monodisperse carbon nanofiber particles were sampled through the APM rotating at a specific speed. Measurements were carried out with particles having mobility sizes ranging from 100 to 700 nm in 50 nm increments. For each size, particle mass was measured by varying the APM voltage while it was rotating at a speed fixed. Effective density, defined as particle mass (measured by APM) divided by particle volume based on mobility diameter, was determined as follows (Park *et al.*, 2003).

$$\rho_{eff}(d_m) = \frac{6m}{\pi d_m^3} = \frac{\rho_0 d_a^2 C(d_a)}{d_m^2 C(d_m)} \quad (1)$$

where ρ_{eff} is the effective density, ρ_0 is the unit density (1 g/cm^3), m is particle mass, d_a is the aerodynamic equivalent diameter, d_m is the mobility equivalent diameter, and C is the slip correction factor.

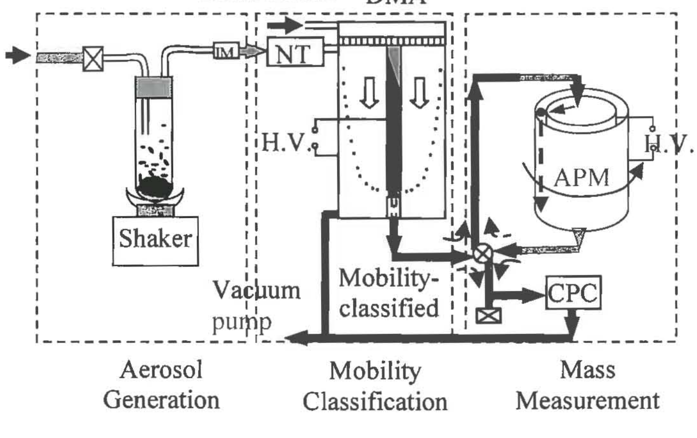

Figure 1. Experimental setup

RESULTS AND DISCUSSION

Figure 2 represents effective densities of carbon nanofibers with sizes ranging from 100 nm up to 700 nm. Each density was obtained by averaging three data samples under the same condition for each particle size. Effective density of carbon nanofibers gradually decreases as mobility diameter increases, with maximum values of about 1.2 g cm^{-3} for particles of 100-150 nm mobility diameters and 0.4 g cm^{-3} for about 700 nm. These results indicate carbon nanofiber particles become more compact as size decreases.

Interestingly, the sudden change in the effective density occurred as the particle size increased from 150 nm to 200 nm. In this size range, effective density also dropped below unit density. According to TEM observation, this sudden change is partly due to onset of agglomeration among nanofibers which resulted in some doubly and triply attached fibers. Figure 2 also includes aerodynamic diameter variation as a function of mobility diameter. Effective density, aerodynamic diameter and mass as a function of mobility diameter for the fibers over the size ranging from 100 nm to 700 nm are summarized in Table 1.

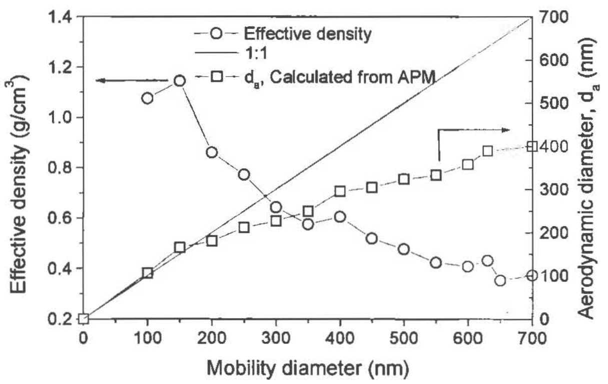

Figure 2. Effective density and aerodynamic diameter of carbon nanofibers as a function of mobility diameter. Effective density data was obtained by averaging three samples from the APM.

Table 1. Effective Densities, Aerodynamic Diameters and Masses of Single Mobility Carbon Nanofiber Particles in the Size Ranging from 100 nm to 700 nm.

Mobility diameter (nm) d_m	Effective density (g cm^{-3}) ρ_{eff}	Aerodynamic diameter * (nm) d_a	Particle mass (fg) m
100	1.08-1.25**	105.8	0.56
150	1.14	165.0	2.02
200	0.86	180.6	3.60
250	0.77	211.3	6.32
300	0.64	226.7	9.10
350	0.58	248.5	12.93
400	0.61	295.4	20.3
450	0.52	304.2	24.78
500	0.48	323.2	31.24
550	0.42	332.8	36.92
600	0.41	357.8	46.3
630	0.43	389.3	56.6
700	0.37	399.3	67.04

* Calculated by using Eq. (1) with known d_m and m

** Effective density has relatively broad values due to low concentration of this size particles.

CONCLUSIONS

The DMA-APM technique has been applied to real-time structure characterization of airborne carbon nanofibers. The effective densities of the carbon nanofibers decreased with increasing mobility diameter, indicating that they have an increasing overall void with increasing mobility size. The results showed that it is important to characterize the structures of airborne materials used for toxicology studies because structure may affect toxicology and does affect transport rates.

Keywords: *Structure Characterization, Airborne Nanofibers, Nanomaterials, Effective Density*

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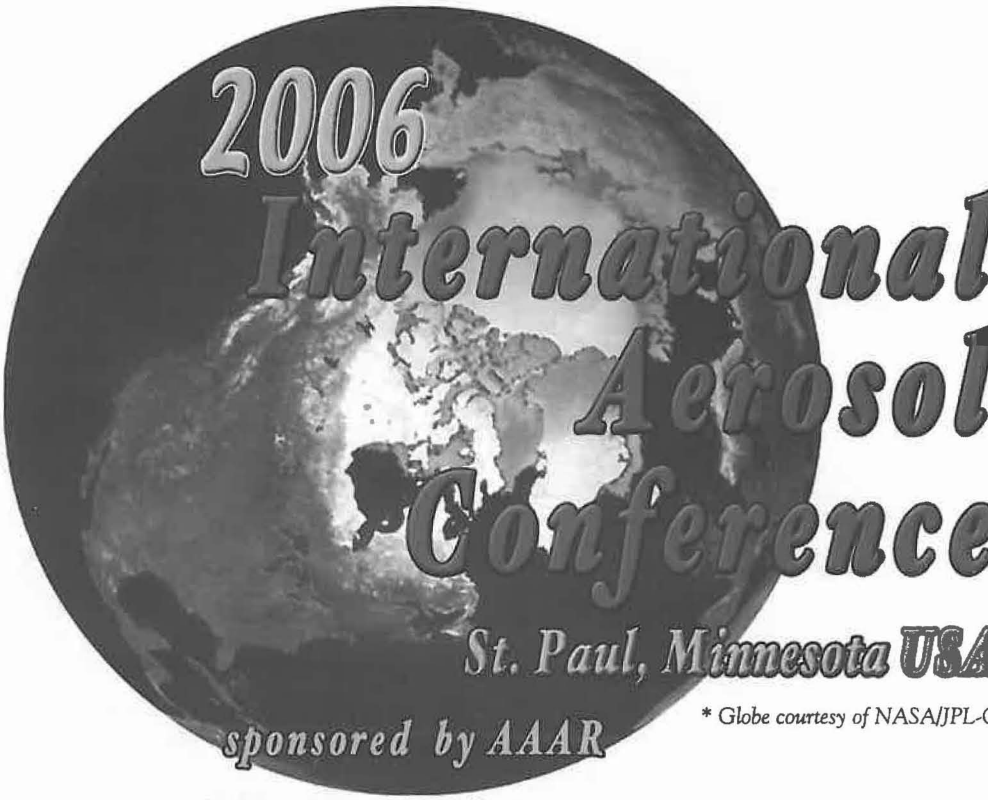

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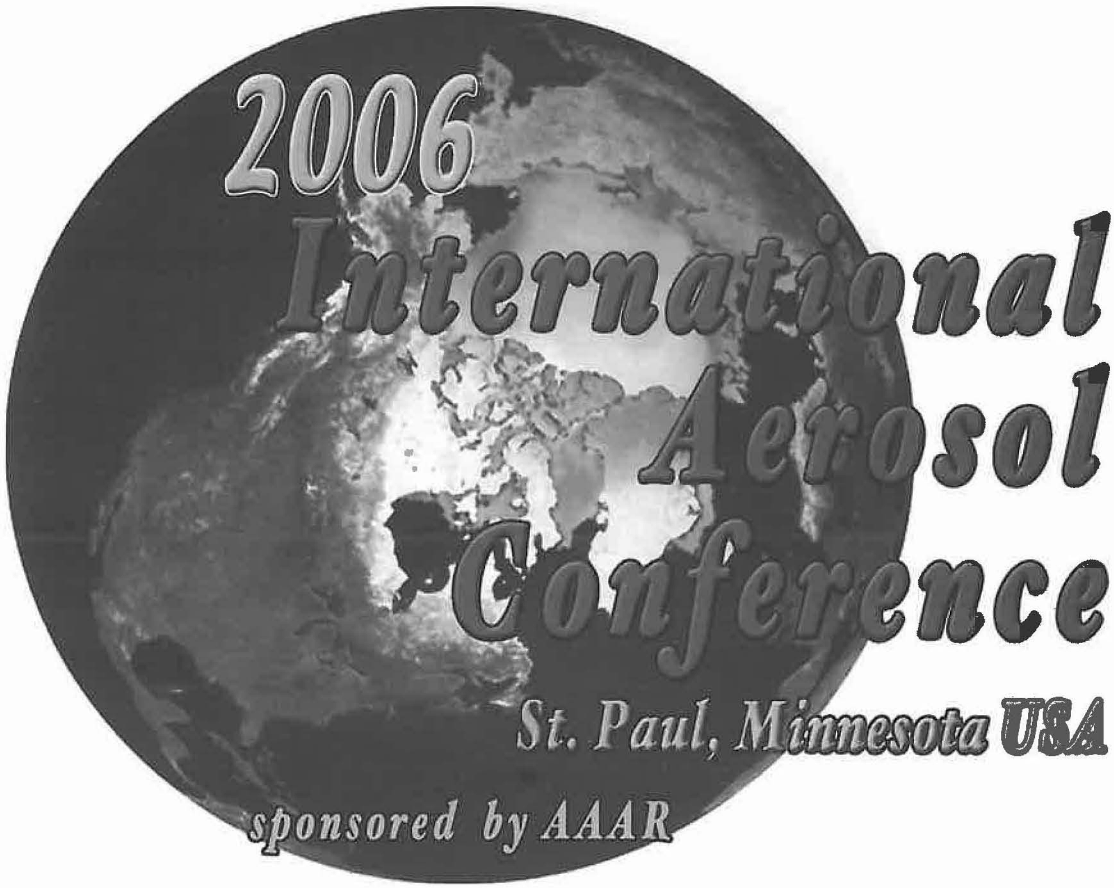

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