Aerosolization of Carbon Nanotubes Using an Acoustic Generator: Particle Generation and Properties

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ABSTRACT

With increasing applications and global production of carbon nanomaterials, there is a growing concern about workplace exposure. The National Institute for Occupational Safety and Health (NIOSH) has recommended a working lifetime exposure limit (REL of 1 µg/m3, 8-h TWA, 45 years) to minimize the potential health risks associated with occupational exposure to carbon nanotubes and nanofibers (CNTs and CNFs) (NIOSH, 2013). Because of the large variety of CNT and CNF products, with varying physical and chemical properties (e.g., highly non-spherical fibrous structures), characterization of their properties and exposure risks is challenging. In addition to work processes, the inhalation risks of carbon nanomaterials depend on material properties, which affect both their toxicity and tendency for air dispersion (Ku et al., 2006). It is therefore important to investigate a variety of carbon nanomaterials to determine: 1) their potential for aerosolization, and 2) the residence time and size distribution of the generated aerosol particles. In this study, we investigated the aerodynamic behavior of CNT powders. The powders were aerosolized using an acoustic generator and their aerodynamic and mobility diameters were determined. Aerosol decay and the characteristics of particle generation were also investigated.

1 INTRODUCTION

With increasing applications and global production of carbon nanomaterials, there is a growing concern about workplace exposure. The National Institute for Occupational Safety and Health (NIOSH) has recommended a working lifetime exposure limit (REL of 1 µg/m^3, 8-h TWA, 45 years) to minimize the potential health risks associated with occupational exposure to carbon nanotubes and nanofibers (CNTs and CNFs) (NIOSH, 2013).

Because of the large variety of CNT and CNF products, with varying physical and chemical properties (e.g., highly non-spherical fibrous structures), characterization of their properties and exposure risks is challenging. Especially important with respect to the inhalation risks is their potential for dispersion in air. Bagging and dumping the manufactured powder in open areas, and cleaning powder containers were identified as activities that presented the greatest exposure risk at a facility manufacturing and processing CNFs (Evans et al., 2010; Birch et al., 2011).

In addition to work processes, the inhalation risks of carbon nanomaterials depend on material properties, which affect both their toxicity and tendency for air dispersion (Ku et al., 2006). It is therefore important to investigate a variety of carbon nanomaterials to determine: 1) their potential for aerosolization, and 2) the residence time and size distribution of the generated aerosol particles. In this study, we investigated the aerodynamic behavior of CNT powders. The powders were aerosolized using an acoustic generator and their aerodynamic and mobility diameters were determined. Aerosol decay and the characteristics of particle generation were also investigated.

2 EXPERIMENTAL METHODS

Test aerosols from one single-walled (SWeNT) and four multi-walled CNT (CNano, Mitsui, NanoTechLabs [NTL], and Bayer Baytubes) powders were generated by an acoustic generator (AG), which is a custom PITT-3 type fluidized bed aerosol generator (AG-5025, Alburty Inc., Drexel, MO). The AG consists of a stainless steel vertical elutriator, latex diaphragm, and speaker. The elutriator section is fully enclosed and sealed with Teflon gaskets. The generator is equipped with a separate module for air flow and audio control, with a frequency response of 30-3000 Hz. The performance of the AG was characterized to find an optimal condition for effectively aerosolizing the CNT powder, which was then fed into a test chamber. The AG was operated at 60 Hz, with low-rate sweeping, and a flow rate of 10

Lpm. Particle size distributions in the chamber were measured continuously by an aerodynamic particle sizer (APS 3321, TSI Inc.) and a scanning mobility particle sizer (SMPS, TSI Inc.) operated at 5 Lpm and 0.3 Lpm, respectively. Total particle number concentration in the chamber was monitored by a Condensation Particle Counter (CPC 3007, TSI Inc.).

3 RESULTS AND CONCLUSIONS

Different CNT materials showed distinct decay characteristics (Fig. 1) of the particle concentration generated by the AG, and decay was found to be correlated with the bulk density of the material. Mean aerodynamic and mobility diameters (d_{ae} and d_m) of the generated particles ranged from 0.79 µm to 2.10 µm, and from 63.8 nm to 317 nm, respectively (Figs. 2 and 3). The mean aerodynamic diameter, which depends on particle morphology and structure, increased with increasing bulk density, but the mobility diameter appeared to follow a reverse trend (Fig. 4).

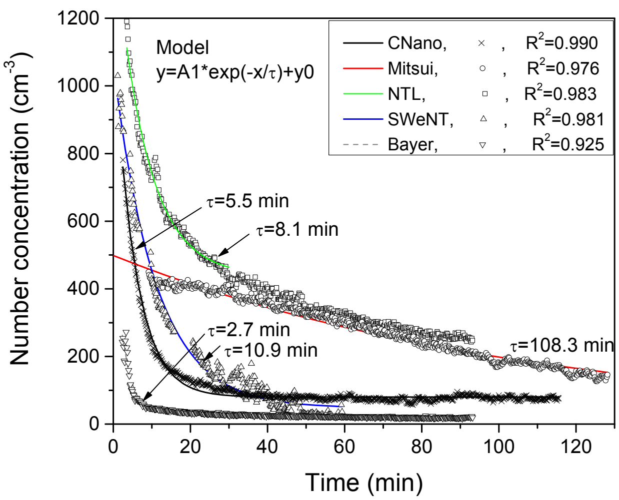

Figure 1. Number concentration as a function of time for different CNT materials. The initial amount of each material tested was 0.2-0.5 g.

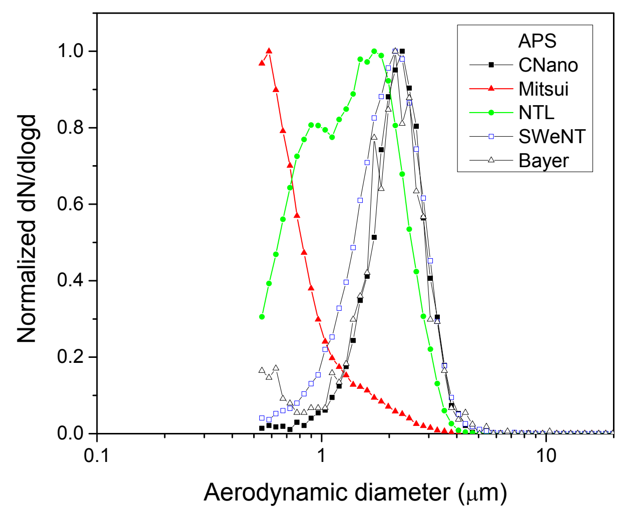

Figure 2. Normalized aerodynamic size distribution of different CNT materials aerosolized by an acoustic generator.

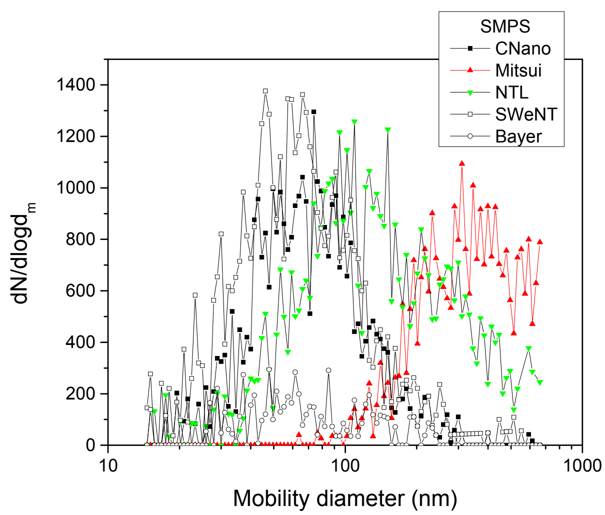

Figure 3. Mobility size distributions of different CNT materials aerosolized by an acoustic generator

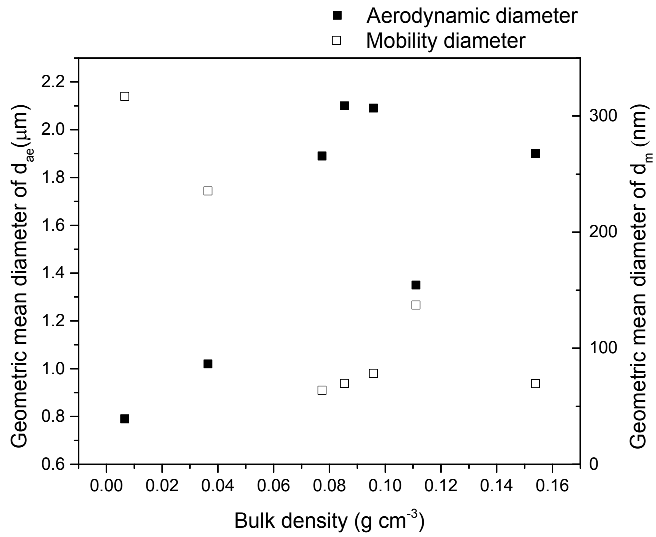

Figure 4. Aerodynamic and mobility diameters as a function of measured bulk density.

Acknowledgments

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