Dustiness testing of engineered nanomaterials

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Abstract. We investigated the dustiness (the propensity of a material to generate airborne dust during its handling) of various nanomaterials, including carbon nanotubes and metal oxides, by the vortex shaker method. The number concentrations and size distributions (~10->10 000 nm) of aerosol particles released during agitation were measured. It was found that the modal diameter was greater than 100 nm for all tested nanomaterials, and for most of them some sub-100 nm particles were observed. The dustiness differed by two (or three) orders of magnitude among the test nanomaterials.

1. Introduction

There is growing concern about the potential health impact of engineered nanomaterials. Inhalation of airborne nanomaterials is potentially a significant exposure route, but there is little information currently available on the nature and magnitude of aerosol releases during manufacturing and handling nanopowders.

In the field of occupational hygiene in the UK, the concept of ‘dustiness’ has been applied to powders. Dustiness is defined as the propensity of a material to generate airborne dust during its handling, and provides a basis for estimating the potential health risk due to inhalation exposure [1, 2]. Various dustiness test methods have been developed; however, they cannot be applied to nanomaterial powders directly because a test which needs smaller quantities of test materials is more suitable for costly nanomaterials or potentially toxic nanomaterials and the dustiness evaluation based on weight concentration is not necessarily adequate to nanosized aerosols.

We built a ‘dustiness tester’ for nanomaterials based on the technique by Maynard et al. [3], which needs only small quantities of test materials for testing (<~1 cm³ of test materials) and simple/compact instrumentation. We have been investigating the dustiness of various nanomaterials, including carbon materials and metal oxides.

We are particularly interested in: (1) the nature of aerosols generated by the technique, (2) the amounts, size distributions, and morphologies of particles released from nanomaterial powders, (3) relative emission/exposure potentials among nanomaterial powders, and (4) the factors that affect the dustiness.

2. Experimental methods

The list of test nanomaterials is shown in Table 1. A schematic diagram of the experimental setup is shown in Figure 1. A spoon (0.25, 0.5, or 1 cm³) of each nanomaterial was placed in a glass test tube and agitated using a laboratory vortex shaker (Vortex Genie 2 Shaker, Cole-Parmer Instrument Co.). The number concentrations and size distributions (~10->10000 nm) of aerosol particles released
during agitation with passing air through the test tube were continuously measured using an optical particle counter (OPC, Handheld 3016, Lighthouse Worldwide Solutions Inc.), an aerodynamic particle sizer (APS 3321, TSI Inc.), and a scanning mobility particle sizer (SMPS) comprising a differential mobility analyzer (DMA 3081, TSI Inc.) and a condensation particle counter (CPC 3010 or 3772, TSI Inc.). The size distribution of nanometer scale particles was characterized using the SMPS (~13-760 nm), and that of larger particles was characterized using the OPC (~300-10 000 nm) and the APS (~700-20 000 nm).

Table 1. List of test nanomaterials.

| Symbol       | Material                  | Trade name, grade          | Manufacturer                                      | Properties                      |
|--------------|---------------------------|----------------------------|---------------------------------------------------|----------------------------------|
| SWCNTs-1     | Single-walled carbon nanotubes | HiPco, as-produced, 35wt% residuals as Fe | Carbon Nanotechnologies, Inc. | Diameter: ~1 nm, Specific surface area: 310 m²/g |
| SWCNTs-2     | Single-walled carbon nanotubes | HiPco, purified            | Carbon Nanotechnologies, Inc. | Diameter: ~1 nm, Specific surface area: 930 m²/g |
| SWCNTs-3     | Single-walled carbon nanotubes | Super Growth               | National Institute of Advanced Industrial Science and Technology (AIST) | Diameter: ~3 nm, Specific surface area: 890 m²/g |
| MWCNTs       | Multi-walled carbon nanotubes |                        | Nikkiso Co., Ltd. | Diameter: ~30 nm, Specific surface area: 69 m²/g |
| Fullerenes   | Fullerene mixture          | nanom mix ST-F             | Frontier Carbon Corporation | Average particle diameter: ~1 µm, Specific surface area: 4.6 m²/g |
| C₆₀          | Fullerene C₆₀              | nanom purple SU, purified  | Frontier Carbon Corporation | Average particle diameter: ~1 µm, Specific surface area: 27 m²/g |
| ZnO          | Zinc oxide                 | FZO-50                     | Ishihara Sangyo Kaisha, Ltd. | Primary particle diameter: ~21 nm, Specific surface area: 32 m²/g |
| TiO₂         | Titanium dioxide           | ST-01, anatase             | Ishihara Sangyo Kaisha, Ltd. | Primary particle diameter: ~7 nm, Specific surface area: 300 m²/g |

Figure 1. Schematic diagram of the experimental setup.

3. Results and discussion
The particle size distributions of aerosols generated from test nanomaterials are shown in Figure 2. Particle sizes are expressed by electrical mobility diameter, optical diameter, and aerodynamic diameter for SMPS, OPC, and APS, respectively. For the particle size distributions by SMPS, unrealistic distribution curves with a dip in the 200-300 nm diameter range were often observed when the multiple charge correction of the SMPS program was turned on, which appear to be due to an artifact by the correction. The modal diameter was greater than 100 nm for all tested nanomaterials, and for most of them some sub-100 nm particles were observed by SMPS.
For most of the test nanomaterials, aerosols were generated over a few hours of agitation and there were no obvious changes in the particle size distributions of aerosols, regardless of the level of agitation and the amount of the test nanomaterials placed in the test tube.

To evaluate differences in dustiness among the test nanomaterials, the number concentrations per the volume and mass of the test nanomaterials placed in the test tube are shown in Figures 3 and 4, respectively. The dustiness differed by two (or three) orders of magnitude among the test nanomaterials. It needs further consideration to determine which indicator is more appropriate.

The relationships between properties of nanomaterials and their dustiness will be investigated in the future.

Figure 2. Particle size distributions of aerosols generated from the test nanomaterials.
4. Conclusions

Aerosol particles generated from various nanomaterials during agitation were measured. The modal diameter was greater than 100 nm for all tested nanomaterials, and for most of them some sub-100 nm particles were observed. The dustiness differed by two (or three) orders of magnitude among the test nanomaterials.

References

[1] Lidén G 2006 Annals of Occupational Hygiene 50(5) 437
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[3] Maynard A D, Baron P A, Foley M, Shvedova A A, Kisin E R and Castranova V 2004 J Toxicol Environ Health A 67(1) 87