Particles Produced By Charge Detonation: Measurement And Analysis

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ABSTRACT

Airborne particles are known to cause respiratory and cardiovascular problems. Although there are regulatory time-weighted limits for particle mass for working (e.g., Exposure Limit) and ambient environments (e.g., PM10, PM2.5), there are little data regarding the size distribution and concentration of particles produced by detonation of explosives that the defense and related industry needs. Several detonation experiments were conducted to determine the properties of aerosol particles generated by explosives that were prepared from conventional and nanophase materials. The initial number concentrations (~ 10^6-10^7 cm^{-3}) of submicrometer particles produced by the detonations of the explosives prepared from nanophase materials were comparable to that produced from the conventional formulation. Near real-time continuous data taken by a time-of-flight aerodynamic sizer and a scanning differential mobility analyzer indicate a multi-modal distribution that there were a peak between 700 and 900 nm, and one and/or two peaks smaller than 100 nm depending upon the explosive used in an individual experiment. The calculated growth rates of particles produced by the explosives in detonation were substantially higher, by two to three orders of magnitudes, than that typically seen in the atmosphere. The implication of the growth rate and its relationship to worker health and safety are discussed.

INTRODUCTION

Aerosol is a term referring to tiny solid and/or liquid airborne particles suspended in the air [1]. An aerosol is an unstable material system with extreme chemical reactivity and population dynamics at production sources, such as detonation of explosives, which produces aerosol particles of diameters smaller than a few micrometers. Nanometer-size particles (diameter ≤ 20 nm), or nanoparticles, posses properties not commonly found in larger particles of the same material. Because of the uncommon chemical (high reactivity, high surface energy, etc.) and physical (optical, thermal, electrical conductivity, etc.) properties of materials at a nanometer scale, the term “nanophase” material has been adapted. With the increased use and interest in producing nanophase materials and/or nanoparticles; however, only limited investigations have been done to obtain exposure data and improve understandings of the biological properties of nanophase materials.

Recent research in particle toxicology has, however, focused on ultrafine and nanoparticles in the ambient atmosphere and work places, because those particles are embedded with toxic agents and have significantly larger surface areas per unit mass compared to micrometer size particles [2, 3, 4]. The materials present in the nanoparticles appear to interact with biological tissues at the cellular level with enhanced reactivity when it is compared to micrometer-size particles of the same material [5, 6, 7]. Exposure to tens of a nanometer-size Ni, Co, and TiO_2 particles has been reported to have enhanced production of free radicals on test tissues and animals causing lung inflammation [8]. Nano-Co and Ni are found to have a similar ability in producing plasmid free radicals and greater ability than that of ultrafine TiO_2.

Thus, for that same health concern, it is reasonable to question the safety of some nanophase materials and the residual particles produced after the application of these materials. The number size distributions of particles derived from detonation of charges prepared from different materials are an important piece of data for investigation of particle toxicity and risk assessment. This paper reports the size distributions, the methods used to obtain the distributions, and aerosol dynamics implication of these data.

MATERIALS AND METHOD

The explosives were prepared by the experts at the High Explosives Research and Development Facility (HERD) at the Eglin Air Force Base (Eglin AFB) in Florida. Four explosives were prepared: one has a conventional formulation, and the other three formulations contain 15-μm, 100-nm, or 50-nm aluminum powder materials. These explosives were detonated in a test chamber at Eglin AFB. During the tests, the chamber was completely isolated with the entrance door tightly closed and secured with a lock. The chamber has been used by HERD for testing a variety of explosives over the past decades. Continuous measurement of the size distributions of airborne particles was made simultaneously using a TSI Scanning Mobility Particle Spectrometer (SMPS®) [9] and a TSI Aerodynamic Time-of-Flight Particle Sizer (APS®). The SMPS was equipped with a long Differential Mobility Analyzer (DMA). The particle size measured by the SMPS ranged from 10 nm to 600 nm; the sampling interval varied from one to three minutes for different test runs. Particles greater than 500 nm up to 10 μm were measured by APS using a 20-second measurement interval. The APS data were averaged to generate data of comparable averaging interval to that of SMPS in the subsequent data analysis. Aerosol measurement instruments were located in an adjacent room separated from the chamber with a shockproof wall. Aerosol particles were drawn from a point about 1-m away from where the charge was located at a 60 liter per minutes flow rate into a homemade manifold. SMPS, APS, and filter measurement were conducted from the manifold. The tubing was conductive silicon tubing connected to a stainless steel sample probe located inside the chamber.

RESULTS AND DISCUSSION

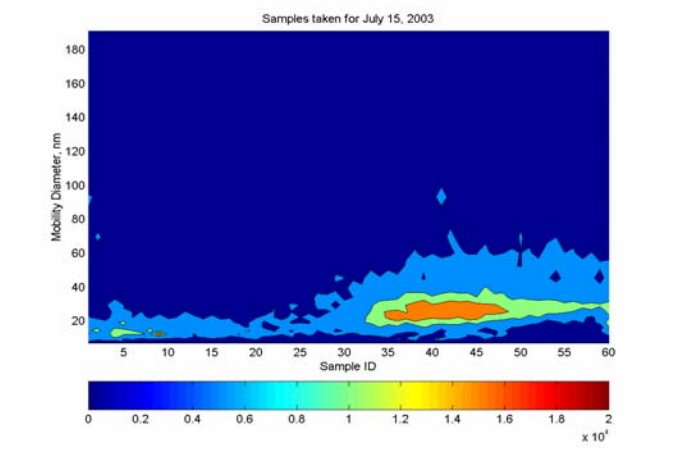
(a) Baseline Particle Characteristics

The baseline condition of the test chamber was measured one day before the detonation experiments were started. No charge was fired on this day. The APS counts (measured at a 20-s interval) were less than 10 cm^{-3} throughout the 3-hr sampling period. The maximum count was

about 3 cm^{-3} occurred only a few times in the period that indicates the chamber had no large particles. The chamber ground is dusty, however, but the loose dirt was not airborne during the sampling.

The SMPS data taken for the baseline case are displayed in Figure 1 in which the particle number concentration is color-coded. The X-axis is the sample ID, and the Y-axis is the mobility diameter in nanometer (nm). The small particles (shown here from 10 to 200 nm) detected by SMPS (ranging from 10 to 600 nm) were mostly less than 40 nm during the first 90 minutes. Dark blue color shows the number of particles in the 10^3 cm^{-3} ranges. After the first 90 minutes (sample ID = 30), a gradual increase in the number concentration of particles less than 80 nm was observed (see Figure 1). We think the moisture from the rain occurred in late afternoon of the previous day might have caused nucleation and condensation. These processes grew smaller nuclei into larger ones that were detected by SMPS. The nuclei source was depleted in 2 hours after the sampling started. The depletion of nuclei resulted in the decrease of the nanoparticle concentration.

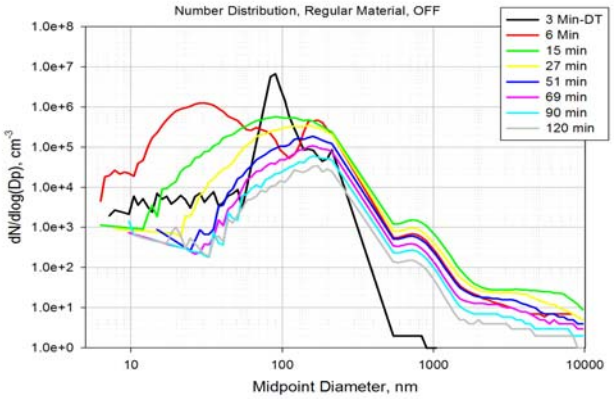
Figure 1. Time-size contour plot for the baseline case at the Dynamic Chamber. The color-coding indicates particle number concentration, dN/dlog (D_p), in the units of # cm^{-3}. Each measurement sample is on a 3-min interval.



(b) Characteristics of Conventional-Charge Particles

The measured number-size distributions over time for the conventional explosives are shown in Figure 2. Each distribution took three minutes to produce. Detonation occurred during the first scan where a peak at 90-nm was found. A bi-modal distribution was found at the second distribution (elapsed time = 3 min). A dominant peak was found at 28 nm and a second peak at 160 nm where the number concentration was approx. 4 times lower than that at 28-nm. The 160-nm peak disappeared in the scan completed at the 15th min. A peak diameter at the neighborhood 90 nm was observed for the particle size distributed recorded twelve min after the detonation. A small single peak was found at 0.7-0.8 μm in the APS data. Particles in this size range are mostly produced by coagulation.

Figure 2. Particle size distributions at various elapsed times (min) for the conventional explosives. Each measurement sample is on a three-min interval.



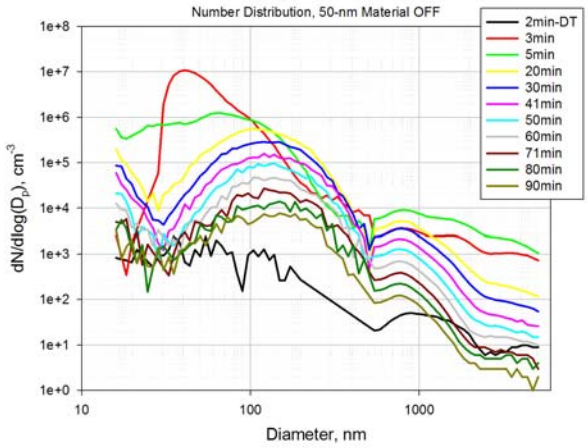
The reduction of particle number concentration is attributed to the conversion of small size particles into large ones by coagulation and possibly deposition to the chamber surfaces, also. The peak size of the single-mode distribution started to increase toward the accumulation-mode region (100 nm -1 μm). The peak size appeared to have stabilized at around 150 nm after 20 minutes. The number concentration for the peak size and the total number concentration for the population continued to decrease.

(c) Characteristics of Particles from the 50-nm Material Charge

Particles resulting from detonation of the 50-nm material charge exhibit, initially, a single-mode distribution with the peak size of 40 nm, much smaller than what was observed for those explosive materials discussed earlier. A couple of minutes after detonation a distribution with a large peak appearing at 67 nm emerged. The distribution was broadened and the number concentration decreased by an order of magnitude (10^7->10^6 cm^{-3}). Subsequent scans show that the growth was completed within ten minutes; the peak stayed at approx. 80-100 nm till ninety minutes after detonation (shown in Figure 3) and throughout entire experiment of 120 minutes (not shown).

The number concentration at the peak continued to decrease after a few min as shown in Figure 3, but at a much slower rate than the first three minutes. In addition, the initial total particle number concentration was about $6x10^6$ cm^{-3} comparable to those previously observed for other explosive. Comparison of the size distributions of the conventional charges, particles from this charge seems to reach a self-preserve distribution much faster. The APS data indicate a separate peak at 700-800 nm range same as that seen for the conventional charge.

Figure 3. Particle size distributions for the 50-nm material explosives. Each measurement sample is on a 1.5-min interval.



CONCLUSIONS

The growth, dynamical change of the size distribution, and the number concentration of nanoparticles produced by the detonation were experimentally characterized. Material properties could play a significant role in the early stage of particle production and enhancement of subsequent particle growth. The properties could have also enhanced the deposition velocity leading to a higher reduction rate of total particle concentrations for explosives prepared from the nanophase materials. The particle growth dynamics and surface deposition removal play significant role in determining the residual amount of particles in the test chamber. The high level of particles in addition to the enriched organic compounds and metal species could raise concern on the safety of the release of these particles into the ambient atmosphere and the potential for worker exposure. The toxicological properties of the detonation particles need to be investigated in the future.

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REFERENCES

1. Friedlander, S.K. *Smoke, Dust, and Haze*, 2nd Ed., Oxford University Press, New York, NY, 2000.
2. Ferin, J., Oberdorster, G., Penney, D.P., Soderholm, S.C., Gelein, R. and Piper, H.C. *J. Aerosol Sci*., **1990**, 21(3), 381-384
3. Oberdorster, G. Ferin, F., Finkelstein, G., Wade, P. and Corson, N. *J. Aerosol Sci*., **1990**, 21(3), 384-387
4. Donaldson, K., Stone, V., Clouter, A., Renwick, L., and MacNee, W. Ultrafine Particles, *Occup. Environ. Med*., **2001**, 58, 211-216.
5. Cheng, M.-D., Malone, B., and Storey, J.M.E. *Chemosphere*, **2003**, 53: 237-243.
6. Huang, S.L., Hsu, M.-K. and Chan, C.-C. *Environ. Health Persp.*, **2003**, 111: 478-482
7. Li, N., Sioutas, C., Cho, A., Schmitz, D., Misra, C., Sempf, J., Yang, M., Oberley, T., Froines, J. and Nel, A. *Environ. Health Persp.*, **2003**, 111:455-460
8. Zhang, Q., Kusaka, Y., Sato, K., Nakakuki, K., Kohyma, N. and Donaldson, K. *J. Tox. and Environ. Health, A*: **1998**, 53: 423-438
9. Wang, S.C. and Flagan, R.C., *Aerosol Sci. Technol*., **1990**, 13:230-240

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