Characterization of worker exposure to carbon nanotubes in an industrial setting

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Abstract

Studies have shown that carbon nanotube (CNT) industry airborne background concentrations of elemental carbon (EC) are typically less than 1 µg m^{-3}, and that an elevated exposure to EC in the workplace may be a reasonable indicator of CNTs exposure [1, 2]. Predominant uptake occurs via inhalation exposure [3-5]. However, the current literature is lacking of direct information on workers' personal exposure to CNTs [2].
In this work, worker exposure to CNTs while manufacturing semi conductive films was assessed. We measured particulate matter concentrations in the size range of 2.5 nm to 10 µm, and gas phase concentrations (CO, CO_2 and O_3). Workers CNTs exposure levels were quantified by analyzing particle samples with the transmission electron microscope (TEM). Continuous measurements were made over eight consecutive days. The work activity took place during weekdays between 8:00 and 17:00. Figure 1 shows the overall trends in (a) total PM and CO concentrations and (b) particle number size distributions. Figure 2 shows a micrograph from the CNTs sampled in workplace air.
During working hours, average PM and CO concentrations were clearly higher than during non-activity hours (1.5 and 2.9 times higher respectively). However, the time series of particle concentrations (see Figure 1) did not reveal consistent trends between any of the direct reading instruments sampling and reactor opening times, when CNTs were expected to be released. Similar findings were reported by Dahm *et al*. (2013) [6]. Thus, collecting samples for analysis by more selective, time-integrated, TEM-based methods should be performed in order to confirm and quantify exposures to CNTs. Although just a rough estimation, TEM analysis revealed workplace air concentrations of 0.0017-5.6 CNTs fibers cm^{-3}, depending on the process. CNTs length varied from several micrometers to tens of micrometers. The thickness of CNTs bundles varied from 10 to 20 nm (see Figure 2) and a single fiber from 2 to 3 nm. Closer examination of micrographs show presence of iron catalyst particles (approximately 10 nm in diameter) attached to nanotubes. Accurate counting of these nanomaterials with TEM micrographs was challenging due to high aspect-to-diameter ratio (length/width > 500) and branching of fibers. Despite this limitation, it may be concluded that there is potential for release of CNTs during manufacturing processes, both under normal operation and during worst case scenarios, e.g., CNTs manufacturing without local exhaust ventilation (LEV) or during cleaning operations. Exposure levels during this work were well below established and proposed limits (1 µg m^{-3} [7] and 0.01 fibers cm^{-3} [8]), except for the worst case scenario (absence of LEV). The correct application of LEV to the collection chambers and the use of sufficient exhaust flow from collection chamber are important for scaling-up of the production.

References

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Figures

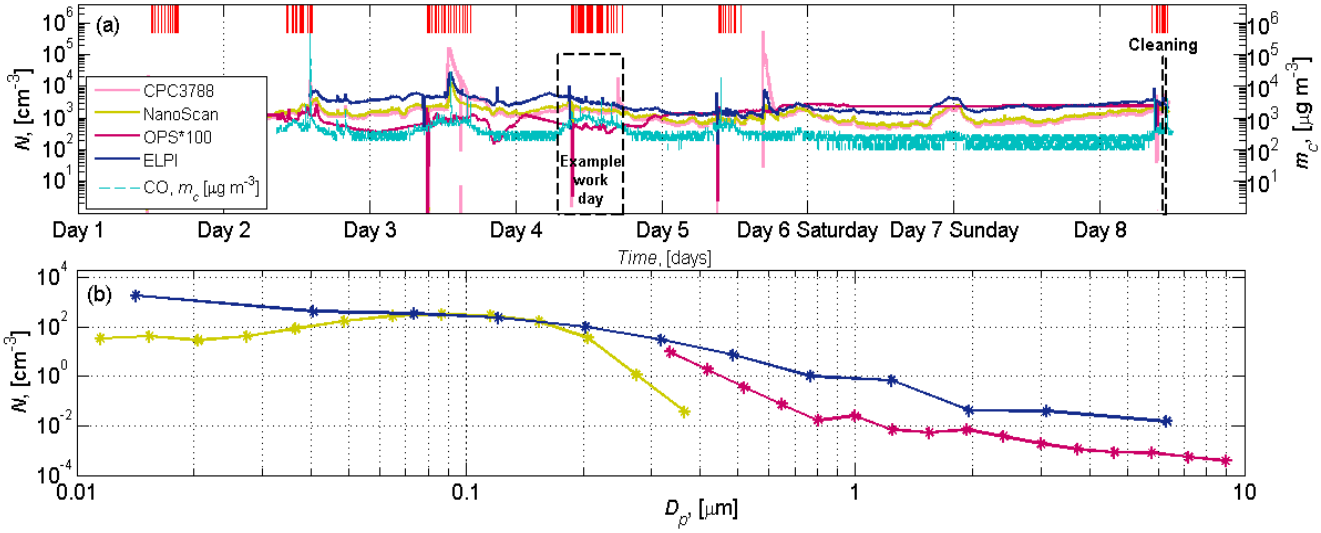

Figure 1 (a) Time series of particle number and CO concentrations and (b) particle number size distributions measured by ELPI, NanoScan and OPS with corresponding color line in (a). The red vertical lines in (a) correspond to reactor opening times when the expected CNTs emissions may occur.

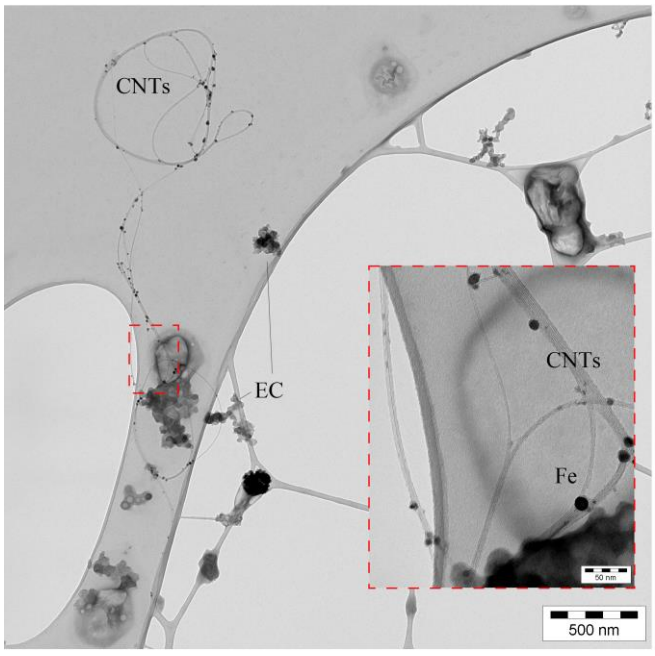

Figure 2 TEM image of CNTs collected in workplace air under normal operating conditions.