Field Application of a Personal Nanoparticle Sampler in Metalworking Industry

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ABSTRACT

This study presents workers' personal exposure to respirable particle (RPM) and nanoparticle mass (NPM) and examines the performance of a newly-developed personal nanoparticle sampler (PENS) in the metalworking industry. Three metalworking plants were selected to characterize exposure during high-speed metal polishing, spot welding and metal milling. Accordingly, the three plants nominally represent sources of solid particles, metal fumes and oil-water mists, respectively. A pair of personal samplers (PENS and SKC aluminum cyclone) was worn by each of the two workers and one mannequin, complemented by environmental monitoring of particle number size distributions, during the entire work shift at each workplace. The results show that common metalworking processes produce low levels of RPM, in reference to exposure limit for nuisance respirable dust, but very high number concentrations of nanoparticles. The NPM levels on average were 14.6±6.1 μg m^{-3}. Comparison of paired sampling results show that the PENS-measured RPM were in excellent agreement with the SKC-measured RPM, whereas the PENS-measured NPM were strongly and moderately correlated with the measured ambient nanoparticle number concentrations and nano-to-total particle volume concentration ratios, respectively. Overall, this study suggests that the PENS are applicable to personal exposure assessment of airborne particles in conventional workplace settings; nevertheless, more varieties of field studies are recommended.

Keywords: *nanoparticles, personal sampler, exposure assessment, metalworking*

1. INTRODUCTION

Nanoparticles are those with sizes smaller than 100 nm and, based on their origins, are broadly classified into two types: environmental nanoparticles or ultrafine particles are those incidentally emitted or produced in the environment, and engineered nanoparticles are those intentionally fabricated in the laboratory or industrial processes. Once become airborne, these very small particles are easily inhaled and efficiently deposited deep in the alveolar region. They have also been linked to adverse human health effects[1].

In the workplace settings, there are a number of sources of nanoparticles. Hot processes, engine combustion and high-speed grinding incidentally produce high number concentrations of nanoparticles[2,3]. The above processes are particularly common in the metalworking industry. Engineered nanoparticles potentially could be released during production, handling, bagging and processing[4]. Apparently, there is an urgent need to characterizing workers' exposure to nanoparticles, in both the traditional and nanotechnology industry.

Present exposure assessment of airborne nanoparticles is still limited to fixed-point or area monitoring[4] because currently available instruments are too bulky for personal exposure measurements. The latter sampling method in particular is more representative of workers' exposure. More recently, a novel personal nanoparticle sampler (PENS) has been developed to simultaneously collect respirable particle mass (RPM) and nanoparticle mass (NPM) on filter substrates[5]. Although it has been calibrated and validated in the laboratory, the PENS has not been fully evaluated in the actual workplaces. With that in mind, the present study aims to determine workers' personal exposure to RPM and NPM and to examine the performance of the PENS in the metalworking industry.

2. EXPERIMENTAL METHODS

Two types of personal sampler were used in this study, the newly developed PENS and the SKC aluminum respirable dust cyclone. The impaction substrates and filters were conditioned at 23±3 °C and 40±5 % for at least 24 hours before weighing. The pre- and post-weighing were carried out using a microbalance with a precision of 1 μg. The particle number size distributions were measured with a sequential mobility particle sizer and condensation particle counter (SMPS+C). The detectable aerosol mobility diameters range from 5.5 to 350.4 nm with a sheath and sample flow of 3 and 0.3 L/min, respectively.

Three metal processing plants were selected to characterize nanoparticle exposure during high-speed metal polishing, spot welding and metal milling. According to the nature of generated particles, the three plants nominally represent sources of solid particles, metal fumes and oil-water mists, respectively.

The sampling strategy consists of workers' personal exposure measurement and fixed-point environmental monitoring. In each plant, two workers (referred to as W1 and W2) at adjacent or nearby (distance within 3 m) workstation were selected for personal exposure measurement. In addition, a full-size mannequin (M) was placed as close as possible (within 1.5 m) to W1. The sampling duration of the personal and environmental measurements covered the full day-shift of 6-8 hours, from 8:00 to 17:00. The entire sampling strategy was carried out twice, over two consecutive days, for each metal processing plant.

3. RESULTS AND DISCUSSION

Figure 1 shows the range of personal exposure to RPM and NPM measured by the PENS, during the three types of metalworking processes. As shown, the RPM were highest and comparable during polishing and welding, whereas they were lower during milling. The NPM were highest and comparable during welding and milling, whereas they were lower during polishing.

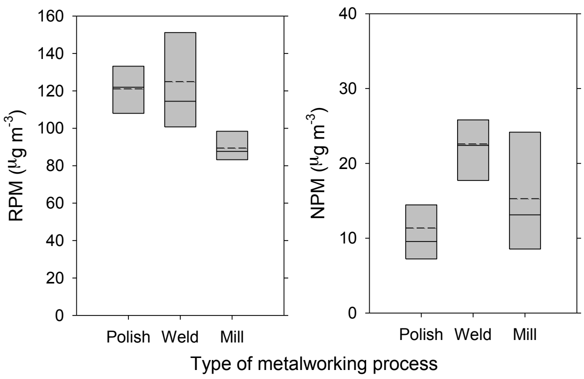

Figure 1. Personal exposure to RPM and NPM during metalworking processes

The ambient NPN at work and rest periods measured in proximity to the work zone of the three types of metalworking processes is shown in Figure 2. The NPN during working periods were mostly in the range of 10^5-10^7 cm^{-3}, between which higher levels were observed during metal welding and milling. In comparison to the levels during rest periods (10^4-10^5 cm^{-3}), it is clear that the three metalworking processes produce high number concentrations of nanoparticles.

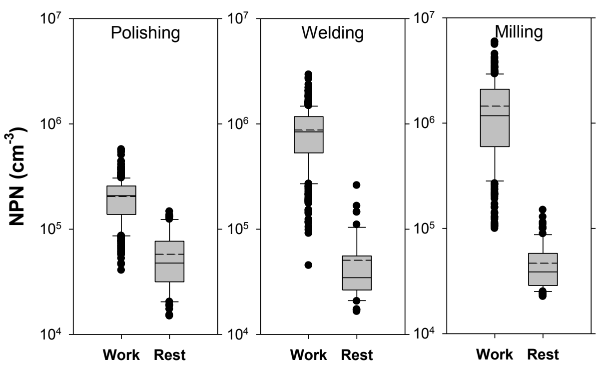

Figure 2. The ambient NPN at work and rest periods during metalworking processes

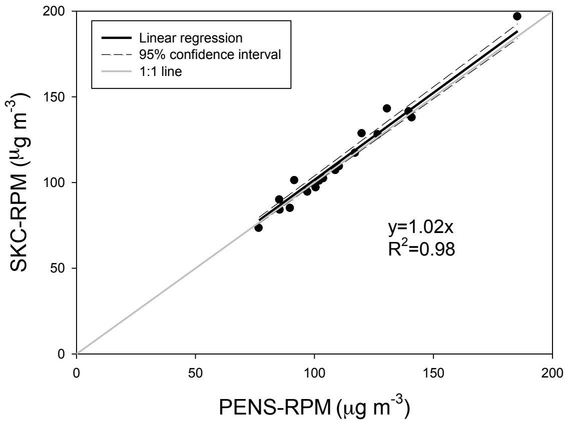

Figure 3. Correlation between the RPM measured by paired PENS and SKC samplers

The correlation between the RPM from paired PENS and SKC samplers is presented in Figure 3. As shown, the PENS-measured RPM show excellent agreement with the SKC-measured RPM (slope=1.02, R^2=0.98). The linear regression indicates, on average, the difference between the two is approximately 2%. As there is no direct validation method, the PENS-measured NPM were compared to the ambient nanoparticle number concentration (NPN), nanoparticle volume concentration (NPV), and the ratio of nanoparticle-to-total particle volume concentration (NPV/TPV) measured by the SMPS. The corresponding correlation matrix is given in Table 1. The NPM shows strong correlation (r=0.81) with the ambient NPN, which is by far the best predictor of NPM. The correlation decreases substantially to r=0.49 when relating the NPM with NPV. This indicates that, without knowing the particle morphology and density, the nanoparticle volume is a rather poor predictor of nanoparticle mass. In addition, the assumption of spherical and unit density particle is thus not appropriate in the workplaces under study. After normalizing the NPV with respect to TPV, the correlation between NPM and NPV/TPV improves to r=0.68. This shows that the NPV/TPV a better estimate of NPM than the NPV alone.

Table 1. Correlation matrix between NPM, NPN, NPV and NPV/TPV

	NPM	NPN	NPV	NPV/TPV
NPM	1.00	-	-	-
NPN	0.81	1.00	-	-
NPV	0.49	0.60	1.00	-
NPV/TPV	0.68	0.89	0.64	1.00

4. CONCLUSIONS

In this study, a newly-developed personal nanoparticle sampler (PENS) is deployed to determine workers' personal exposure to respirable particle (RPM) and nanoparticle mass (NPM) and to examine the performance of PENS in the metalworking industry. The results show that common metalworking processes produce considerably low levels of RPM, but very high number concentrations of nanoparticles. Comparison of paired sampling results show that the PENS-measured RPM are in excellent agreement with the SKC-measured RPM, whereas the PENS-measured NPM were strongly and moderately correlated with the measured ambient nanoparticle number concentrations and nano-to-total particle volume concentration ratios, respectively. This study therefore suggests that the PENS are applicable to personal exposure assessment of airborne particles in conventional workplace settings; nevertheless, more varieties of field studies are recommended.

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REFERENCES

1. Kreyling, W. G., Semmler-Behnke, M. and Möller, W. Health implications of nanoparticles. *Journal of Nanoparticle Research*, 8, 543–562 (2006).
2. Zimmer, A. T. and Biswas, P. Characterization of the aerosols resulting from arc welding processes. *Journal of Aerosol Science*, 32, 993–1008 (2001).
3. Zimmer, A. T. Investigation of the aerosols produced by a high-speed, hand-held grinder using various substrates. *Annals of Occupational Hygiene*, 46, 663–672 (2002).
4. Kuhlbusch, T., Asbach, C. and Fissan, H. Nanoparticle exposure at nanotechnology workplaces: a review. *Particle and Fibre Toxicology*, 8, 22 (2011).
5. Tsai, C.-J., Liu, C.-N., Hung, S.-M., Chen, S.-C., Uang, S.-N., Cheng, Y.-S. and Zhou, Y. Novel active personal nanoparticle sampler for the exposure assessment of nanoparticles in workplaces. *Environmental Science and Technology*, 46, 4546–4552 (2012).