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Original Article

Comparison of Real Time Nanoparticle Monitoring Instruments in the Workplaces

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ABSTRACT

Background: Relationships among portable scanning mobility particle sizer (P-SMPS), condensation particle counter (CPC), and surface area monitor (SAM), which are different metric measurement devices, were investigated, and two widely used research grade (RG)-SMPSs were compared to harmonize the measurement protocols.

Methods: Pearson correlation analysis was performed to compare the relation between P-SMPS, CPC, and SAM and two common RG-SMPS.

Results: For laboratory and engineered nanoparticle (ENP) workplaces, correlation among devices showed good relationships. Correlation among devices was fair in unintended nanoparticle (UNP)-emitting workplaces. This is partly explained by the fact that shape of particles was not spherical, although calibration of sampling instruments was performed using spherical particles and the concentration was very high at the UNP workplaces to allow them to aggregate more easily. Chain-like particles were found by scanning electron microscope in UNP workplaces. The CPC or SAM could be used as an alternative instrument instead of SMPS at the ENP-handling workplaces. At the UNP workplaces, where concentration is high, real-time instruments should be used with caution. There are significant differences between the two SMPSs tested. TSI SMPS showed about 20% higher concentration than the Grimm SMPS in all workplaces.

Conclusions: For nanoparticle measurement, CPC and SAM might be useful to find source of emission at laboratory and ENP workplaces instead of P-SMPS in the first stage. An SMPS is required to measure with high accuracy. Caution is necessary when comparing data from different nanoparticle measurement devices and RG-SMPSs.

1. Introduction

Traditionally, gravimetric sampling which collect the airborne particles on a filter, has been used to assess the workplace. However, nanoparticles are difficult to evaluate by gravimetric sampling Q2 because they are very small to affect the mass concentration and it is difficult to find the source of emission during working time. Therefore, many real-time monitoring devices are available to measure airborne nanoparticles, such as scanning mobility particle sizer (SMPS), condensation particle counter (CPC), and surface area monitor (SAM). There is a controversial issue in measurement metrics in exposure assessment as well as toxicity [1–3]. For this reason, many researchers have employed a combination of measurement devices for nanoparticle exposure assessment and it is necessary to investigate the level of concentration with several metrics [4–9].

SMPS, CPC, and SAM are the most common combinations for nanoparticle exposure assessment at workplaces [4,9,10]. Research

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grade (RG)-SMPSs, such as Grimm 5.403+C (Grimm Technologies, Douglasville, GA, USA) and TSI Model 3936L75 (TSI, Shoreview, MN, USA), remain the golden standard of aerosol instrumentation even 20 years after their invention. They measure aerosol size distributions with high accuracy, but have long time resolution, and thus cannot be used to measure rapidly changing particle size distributions at workplace because scanning time is over 2 minutes [11]. However, RG-SMPSs are expensive and heavy to move to the sampling site; a portable SMPS (TSI Model 3910 with 1-minute time interval), hereafter referred to as P-SMPS, is cheaper than RG-SMPS, but still expensive [11]. It is necessary to find a possible surrogate measurement device to measure nanoparticles. CPC and SAM are relatively cheaper than SMPS and portable. To compare and find relationships among SMPS, CPC, and SAM, correlation analysis is necessary.

When the number concentration is measured, the measurement devices have different size and concentration ranges. In exposure assessment studies, the potentially different results from different instruments are issues when results obtained simultaneously at the same location or different locations [12]. Two common RG-SMPSs are manufactured by Grimm and TSI [13]. They have different techniques to separate particles size: Grimm SMPS measures large particles to small particles in size and TSI SMPS measures particles from small particles to large particles. Also, sampling time is different between SMPSs. Differences may occur in the concentration when nanoparticles at the same location is measured with different SMPSs. Therefore, harmonization and investigation of difference of devices is necessary and getting the relationships between same metric measurement devices is essential for use of exposure assessment data in the future [14]. There are a few studies that compare nanoparticles measurement instruments in the -controlled laboratories [14,15] and no studies at workplaces to our knowledge.

The aims of this study were to determine relation among three monitoring devices of nanoparticles—SMPS, CPC, and SAM—and compare two widely used RG-SMPS for better understanding of nanoparticle measurement devices.

2. Materials and methods

2.1. Sampling facility

Three types of workplace were categorized: laboratory (LAB); engineered nanoparticle (ENP) workplace; and unintended nanoparticle (UNP)-emitting workplaces (Table 1). A total of nine workplaces participated.

Three laboratories at a university were investigated. LAB-A was an earth environment laboratory, and the primary nanoparticle was Al_2O_3. Two workers performed experiments of transfer to the crucible, transfer from the crucible to a vial, and weighing. LAB-B was involved with development of new materials, with the primary nanoparticles used being Fe_2O_3 and TiO_2. Major experiments were weighing, sonication, and reaction. Seven workers performed the experiments. LAB-C dealt with graphene for space aviation. Dip-coating processes to fabricate graphene were the primary experiments performed; together with spraying the base of the dip coater for cleaning by five workers. A natural ventilation system and a fume hood were installed in all laboratories.

Three ENP manufacturing workplaces examined. ENP-D fabricated Ti and Zn powder for cosmetic sunscreen; reaction, dehydration, mixing, drying, and bagging were the major processes at ENP-D. The reaction was operated at 120°C and 3 atm, and dehydration was performed at 60°C. There were a natural ventilation (NV) system and no local exhaust ventilation (LEV). TiO_2 was extracted from $TiCl_4$ for the photocatalyst material. The liquid-phase TiO_2 was synthesized

Table 1
The general characteristics of workplaces

Workplace		Emitted/source of nanoparticles	Ventilation type	Process/task	Production rate	Workplace area (m^2)	No. of nanoparticle handling workers	Possible other sources	Sampling duration
LAB	A	Al_2O_3	GV, fume hood	Transferred to crucible, transferred from crucible to vial, weighing	–	120	2	–	One shift + one off-duty time
	B	Fe_2O_3, TiO_2	GV, fume hood	Weighing, sonication, Reaction	–	78	7	–	One shift + one off-duty time
	C	Graphene	GV, fume hood	Spraying air using compressor, dip-coater	–	90	5	–	One shift + one off-duty time
ENP	D	TiO_2, ZnO	GV	Reaction, dehydration, mixing, drying, bagging, lunch	TiO_2: 10 ton/y ZnO: 50 ton/y	1,400	10	Fork lift	Two day shifts + one night shift
	E	Cu-Ni alloy, Ni	LEV and isolation	Collecting, sieving, lunch	Ni: 100 kg/y Cu—Ni: 100 kg/y	97	6	–	One shift
	F	Fumed silica	LEV, GV	Packaging, meal (lunch, dinner), break time, night shift - no works, outdoor, warehouse	9,000 ton/y	3,500	12	Fork lift	Two day shifts + one night shift
UNP	G	Welding (Arc, SUS)	GV	Arc welding, SUS welding, break time, lunch	–	Arc: 10,000 SUS: 820	100	Fork lift	Two day shifts
	H	Welding (Arc)	GV	Arc welding, grinding (day shift, night shift), lunch	–	2,017	30	Fork lift	Two day shifts + one night shift
	I	Smelting process, Welding (Arc)	GV	Smelting, welding, break time, lunch	–	11,000	Smelting: 15/shift × 2 welding: 3	Fork lift	Two day shifts + one night shift

ENP, engineered nanoparticle manufacturing workplace; GV, general ventilation; LAB, laboratory; LEV, local exhaust ventilation; UNP, unintended nanoparticle emitted workplace.