Workplace Based Sampler Comparison Review

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A narrative review on peer-reviewed literature reporting comparisons of personal samplers in workplace settings published between 2004 and 2020 was carried out. Search terms were developed for Web of Science and PubMed bibliographic databases. The retrieved studies were screened for relevance, with those studies meeting the inclusion criteria being taken forward to data extraction (22 studies). The inhalable fraction was the most common fraction assessed, with the IOM sampler being the most studied sampler. The most common workplace environment where samplers had been compared was that where metals/metalloids were present. The requirements of EN13205 standard (Workplace exposure. Assessment of sampler performance for measurement of airborne particle concentrations) have also been considered, with these requirements not currently being met, or at least referred to, in the reviewed literature. A number of conclusions have been drawn from this narrative review. For studies that reported correction factors, no discernible trends could be identified.

inhalable respirable thoracic aerosol particulates comparison performance inter-sampler EN13205 workplace

1. Introduction

Exposure to hazardous substances may occur in the workplace in the form of aerosols. The term ‘aerosol’ is used to describe any suspension of particles in air, and most aerosols consist of a wide range of particle diameters. The British Medical Research Council definition of the respirable aerosol fraction (those particles with a median aerodynamic diameter of 5 µm collected with a 50% efficiency) was the first recognized internationally [1]. In 1989, new criterions for aerosol fractions were proposed by Soderholm [2] and international collaboration led to the agreement on the definitions of health-related aerosol fractions in the workplace, defined as inhalable, thoracic, and respirable, that relate to the region of the respiratory tract where they are most likely to deposit. The convention for these size fractions is described in ISO 7708 [3].

Regulatory bodies and research institutions have increasingly lowered occupational exposure limit values (OELVs) in response to increased understanding of health effects and routes of exposure [4][5][6]. However, these OELVs are chosen with the health of the worker in mind rather than technical or analytical feasibility [7]. An additional complicating factor is that research has recognized that differently sized fractions of particles have different health impacts, which has required refining of the sampling process to detect air concentration levels of each fraction. Low OELVs and the need to differentiate between size-selective fractions present a unique challenge to industrial

hygienists, epidemiologists, and occupational safety specialists. All aspects of determining the presence of a hazardous substance, including sampling, sample dissolution, and the analytical methods themselves, must be optimized to attain these lower limits precisely and accurately [8].

A recent survey of aerosol sampling heads used within the metals industry (personal communication, S Verpaele) was done in parallel to a survey of European laboratories concerning the methods used for the determination of nickel in workplace air [9]. This survey revealed a wide variety of inhalable, thoracic, and respirable samplers as being commonly used.

In April 2019, the Nickel Institute, a global association of primary nickel producers, held a meeting with interested parties regarding the development or adaptation of existing sampling trains to measure low levels of metals and metalloids in the workplace. The parties involved agreed on the need for an international sampler comparison study. The main objective of this international study is to compare currently used (and validate any newly developed) personal samplers for measuring particulate related exposure (and more specifically metals and metalloids) in workplace settings. Sampler efficiencies for relevant aerosol size fractions of those samplers currently on the market will also be included in this study [10].

Within the framework, two stakeholder groups were created. The first is the Sampler Comparison Industry Group including industry stakeholders. The tasks of this group are related to foreseeing budget, making sure the industry is represented and their needs identified and that they engage with their members and individual companies about the project. The second is the Sampler Comparison Scientific Group including those involved in research institutes and universities. In this group, the project plans are established and executed. An important task for both groups is to identify worldwide research grants that can be applicable to this project. The first project granted within this framework was a WorkSafe British Columbia (Canada) project to compare the most commonly used sampling techniques with more advanced sampling techniques for metals and metalloids in North America. In parallel, protocols for testing respirable and inhalable samplers in laboratory test chambers are being developed and this literature review, which aims to summarise the literature describing sampler comparison studies in workplace settings, along with a further review focused on laboratory comparison and efficiency studies, are being executed. The long-term aim of the overarching international sampler comparison study is to ensure exposure data which is used on epidemiological studies is both precise and aligned for use in the setting of OELVs.

Various historic studies have been published comparing the performance of different samplers [11][12][13][14][15][16][17][18][19][20][21][22][23]. Findings suggest that using different samplers can result in significant differences in the observed particle concentration. Wind velocity and direction, inlet size, geometry, orientation, aerosol particle size, electrical charge, particle bounce properties, the sampler conductive properties along with other factors have been identified to affect the performance of samplers [24]. The varying performance of different sampling devices may cause a degree of uncertainty when using the sampling results to check compliance with regulatory limits, or when the data are used for risk assessment and management purposes.

The purpose of the EN13205 standard (first published in 2002) is to allow both manufacturers and users to use a consistent approach for sampler validation and to provide a framework for assessing sampler performance in adherence to standards EN481 [25] and EN482 [26]. Since its first publication this standard has been updated on one occasion in 2014 (EN 13205:2014). The current standard consists of six separate parts: Part 1 which sets the general requirement, Part 2 for performing laboratory based tests which is based on sampling efficiency determination, Part 3 which sets out the requirements for the analysis of sampling efficiency data, Part 4 which sets out the requirements for performing laboratory performance tests for concentration comparisons, Part 5 which sets out the requirements for workplace-based sampler comparison and performance tests, and Part 6 which concerns the transport and handling tests.

The requirements, relevant to this review are those in Part 5 of the standard. Some general requirements are set out for personal samplers for inhalable, thoracic, and respirable aerosol fractions and static sampling with respect to the location of the samplers during the test. For the performance of samplers in the workplace, a comparison between concentrations sampled from a specific workplace should be performed between a candidate sampler and a previously validated sampler.

EN 13205:2014 describes a number of requirements for performing workplace-based sampler comparisons and these are summarised in **Table 1**.

Table 1. Selected Experimental Requirements for EN13025:5 for workplace sampler performance [27].

Parameter	Description
Number of experiments	The standard requires that four sets of experiments (consisting of five runs and parallel sampling) are performed. The parallel runs set out in the standard to be performed are between the candidate and validated samplers, for a least six candidate specimens for the personal sampler, the determination of the effect of flow rate excursions on the mass fraction samples, and the determination of internally separated mass or the collected mass effect. It is also required, under the standard that a validated sampler is needed to be used for two of the experiments.
Candidate sampler bias	For complying with the standard, the exclusion of outliers is allowed. However, a minimum of five different experimental runs for validated sampler/candidate sampler are required to be used.
Candidate sampler variability (not applicable for inhalable fraction and large static samplers)	The standard discusses that this test is not necessary if the candidate sampler is for personal inhalable sampling or if the candidate sampler is a large static sampler.
Exclusion from the nominal flow rate (not applicable for inhalable fractions)	The standard sets out the requirements for sampling the respirable and thoracic fraction. This involves calculating the corresponding uncertainty component. This requirement of the standard is not applicable for sampling the personal inhalable fraction.

Parameter	Description
Collected mass or internally separated mass	The standard discusses that the tests required for collecting the mass and internally separated mass can be performed simultaneously. If the inhalable fraction is being sampled, it is stated that the second test is not required. The components to be calculated are the maximum collected mass and the maximum internally separated mass.
Sampler bias and expanded uncertainty	The criterion for applying a correction factor is stated in the standard for a candidate sampler to be validated. The correction factor from the manufacturer can be used or a correction factor obtained from a relevant measuring procedure. In cases of no correction factor being stated, the standard stated a value of 1.00 should be used.

personal samplers used in workplace settings published between 2004 and 2020, with a focus on those that are used for sampling metals and metalloids. The literature has also been compared to the requirements of EN13205, to identify potential gaps in the experimental requirements with respect to this standard.

2. Samplers Assessed

This present article provides a review of workplace sampler comparison studies available in the peer-reviewed literature published between 2004–2020.

The most common particulate fraction assessed is the inhalable fraction in more than two third of the articles. This finding is expectant. The inhalation fraction is the primary aerosol fraction of interest. This is primarily due to OELVs, threshold limit values (TLV) and other limit values which primarily refer to the inhalable fraction. For example, the limit values for lead and inorganic compounds including in the EU, Canada, Japan, China, South Korea, and the USA are based on the inhalable fraction [8]. The most common inhalable sampler studied is the IOM inhalable sampler (56%) followed by the Button sampler. The IOM sampler is most frequently considered to be the 'gold standard' sampler for the inhalable fraction [9].

A third of the articles compared samplers for the respirable fraction with cyclones (such as the SKC Aluminium cyclone) used. There has also been an increasing interest for assessing the respirable fraction in the metals industry, based on specific toxicological endpoints [6][28][29]. It is therefore important that a good body of evidence is available for how the different respirable samplers compare with each other for measurements in the metals industry. Further work to expand this evidence for respirable samplers in the metals industry is required.

The only thoracic only sampler used has been the GK2.69 cyclone. In approximately 40% of the articles, the total fraction has been assessed, with the 37-mm CFC most commonly used. Some samplers have only been used in one article which does not allow the sampler results to be cross-referenced with other articles.

3. Comparison of Samplers Reported in the Literature and Those Used by Industry

CEN TR 15230 [30] gives a very good overview of the available sampling techniques used 15 years ago complying with the inhalable, thoracic, and respirable fractions as defined in the earlier mentioned standards. Since then, limit

values for metals and metalloids have been proposed and set following those conventional fractions, new sampling systems came on the market and for many there are no comparison studies available nor is it clear whether they all meet the sampling efficiency requirements. When comparing the samplers reported in the literature and those used within the metals industry (personal communication, S Verpaele), a large number of samplers have not been identified in literature for sampler comparison studies:

- Inhalable samplers: Open face cassette (OFC) 25 mm, Zefon inhalable sampler, HSE 7H sampler, and the 37 mm conical inhalable sampler (CIS);
- Respirable samplers: FSP2, SKC conductive plastic cyclone, Zefon cyclones. GS-1 and GS-3 respirable cyclones, SKC disposable, and aluminium respirable PPI samplers, and the 10 mm Dorr-Oliver Nylon Cyclone;
- Multifraction samplers: EA sampling system;
- PM fractions: SKC personal environment monitors for PM2.5 and PM10, SKC PM2.5, and PM10 IMPACT samplers, SKC PM coarse IMPACT sampler and SKC personal modular impactor (PMI) samplers for PM2.5 and PM10.

This review is limited in timescales (2004–2020), so it may be the case that some published studies on these samplers are potentially available. Complementary searches were performed for these samplers to identify potentially relevant sampler comparison studies for these samplers pre-2004 in PubMed. No relevant studies were easily identified. This is a key data gap in the literature and illustrates the requirement of an international sampler comparison study to be undertaken.

4. EN Standard 13025:5 for Workplace Sampler Comparison Studies

The requirements for workplace sampler comparison in EN13025:5 for workplace sampler performance should be followed and for the majority of the studies considered in this review the requirements of this standard were not discussed (or standard even referred to). Authors should be referring to these standards for performing workplace sampler comparison studies and ensuring the appropriate experiments are being performed and recorded. In fact, only one article [31] refers to the standard.

Using the standard will also allow the generation of correction factors which can then be applied to data. This will also allow data to be pooled and also used for comparison purposes.

Table 2. Comparison of studies with requirements of EN 13205:5 standard. (Note: U: unclear if meets requirement; P: partly meets requirement; x: does not meet requirement; N/A requirement not applicable).

Reference	Reference to EN 13205 Standard	Number of Experiments (as Stated in the Standard)	Candidate Sampler Bias	Candidate Sampler Variability	Exclusion from the Nominal Flow Rate	Collected Mass or Internally Separated Mass	Sampler Bias and Expanded Uncertainty
[32]	x	U	U	x	N/A (inhalable) x (respirable)	x	x
[33]	x	U	U	x	N/A (inhalable) x (respirable)	x	x
[34]	x	U	U	x	N/A (inhalable) x (respirable)	x	P
[35]	x	U	U	N/A	N/A	x	P
[36]	x	U	U	x	N/A (inhalable) x (total)	x	x
[37]	x	U	U	N/A	N/A	x	x
[38]	x	U	U	N/A	N/A	x	P
[39]	x	U	U	N/A	N/A	x	P
[40]	x	U	U	x	N/A (inhalable) x (total)	x	P
[41]	x	U	U	x	N/A (inhalable) x (respirable)	x	P
[42]	x	U	U	x	N/A (inhalable) x (total, thoracic, respirable)	x	x
[43]	x	U	U	x	N/A (inhalable) x	x	x

Reference	Reference to EN 13205 Standard	Number of Experiments (as Stated in the Standard)	Candidate Sampler Bias	Candidate Sampler Variability	Exclusion from the Nominal Flow Rate	Collected Mass or Internally Separated Mass	Sampler Bias and Expanded Uncertainty
					(respirable, total)		
[44]	x	U	U	x	N/A (inhalable) x (respirable, thoracic)	x	P
[45]	x	U	U	x	N/A (inhalable) x (respirable, thoracic)	x	P
[46]	x	U	U	x	N/A (inhalable) x (total)	x	P
[47]	x	U	U	x	N/A (inhalable) x (respirable)	x	P
[48]	x	U	U	x	N/A (inhalable) x (total)	x	P
[49]	x	U	U	N/A	N/A	x	P
[31]	√	U	U	N/A	N/A	x	x
[50]	x	U	U	x	N/A (inhalable) x (total)	x	P
[51] [43][46]	x	U	U	x	x (total)	x	x
[52] [36][37][38][39][44]	x	U	U	x	x [34][47]	x	x

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In agriculture settings the differences between the samplers was insignificant [34]. In brick manufacturing, one aspect that needs to be considered is the type of dust that is being sampled [41]. The respirable fraction was sampled in four identified articles with the thoracic fractions assessed in six articles where the Respicon sampler was used in 50% of these articles.

Only a limited number of metal dusts have been assessed (six in total - aluminium, beryllium, copper, lead, tin, and general metal) which suggests a potential research gap for assessing the most appropriate sampler to be used for

measuring other metal dusts. For beryllium dust, one article has recommended that the use of inhalable measurements until a dose–response curve has been undertaken for the sampler heads for the respirable and thoracic fractions [43]. Oversampling and under sampling are potential aspects that has been highlighted for sampling dusts, for example for lead, the respirable fraction has been overestimated by the IOSH cyclone [45]. In the case of under sampling, a number of samplers underestimated rubber dust [31]. Sampling location can also affect the sampler comparison which was observed by Lee et al. [52] for copper dust, where there was statistically significant differences between the area measurements but not for personal measurements. In workplace settings, measurements in wood environments have been undertaken allowing a greater sampler comparison to be undertaken. In a number of cases, the samplers produced similar results such as the ACCU-CAP, Button, CIP10-L, GSP, and IOM samplers [39]. This was also the case for the Italian Cone sampler and the IOM sampler for the inhalable fraction for wood dust [38].

For correction factors reported, no trends could be identified between samplers and settings which further illustrates the need to follow the standard so that correction factors are performed in a similar manner.

6. Limitations Identified by Article Authors

A number of limitations have been identified by the authors of the included articles. Limitations with foam inserts have been identified in two studies. De Vocht et al. [41] identified that clay particulates could stick to the insert or together. Lee et al. [52] also identified that using a customized insert in a cellulosic sampler may not be appropriate for gravimetric analysis due to changes in humidity and mass variabilities. Potential errors from the wiping process of the samplers has been highlighted by Lee et al. [49] such as an inconsistent pressure being applied for wiping the cap inside and internal walls. The sampler location has been noted by Lee et al. [39] as a potential issue with one sampler (CFC) moving position during the sampling process, from the opener facing a 45 degree angle to the vertical at the beginning to being observed to be pointing face outward from the body at the end of the sampling. Potential under sampling has been highlighted by Campopiano et al. [38], as only the particles on the sampling substrate were determined with the wall deposition not considered for the IOM cassette.

7. Potential Improvements

From this review, a number of aspects were identified that need to be considered by both article authors and journal reviewers as part of the peer-reviewing process. The first aspect concerns the EN 13205 standard. It is clear from this review that the requirements of the standard are not being met as suggested by the contents of the peer-reviewed publication. Particularly, in the cases for the number of experiments and sampler bias, it was not clear in the included articles if these requirements are being met.

Following on from the collected mass or internally separated mass requirement of EN13205, the contribution of wall deposits needs to be discussed by authors. The inclusion of wall deposits has been taken into account for the sampled mass in studies such as Lee et al. [49] where the internal walls were wiped and the mass of the wipes

include and Anthony et al. [34], where an internal capsule was used to collect wall deposits for a prototype sampler. A number of studies included in our review have mentioned wall deposits; however, they have not included the contribution of wall deposits in the results [40][43]. Also, a number of studies include no discussion on wall deposits. The issue of dealing wall losses is an ongoing challenge [5].

It is considered that more detailed information is required on the samplers to be included by article authors, and if not included, requested by reviewers. This includes information on cassette materials, for example, in the case of the IOM sampler, where in some cases it is not stated if a plastic or stainless-steel cassette has been used. Flow rates also need to be included for the samplers used, even if only the recommended flow rates for the samplers are used.

Other areas identified which need to be considered are handling of cassettes / filter materials, wiping of cassettes (where appropriate), storage of filter materials and sampling duration needs to be explicitly clear.

Developed samplers should also be named to allow data tracking for the sampler to occur. This was the case for one sampler that was developed by L'Orange et al. [53] which has subsequently been tested by Anthony et al. [34] using a different name (prototype high-flow inhalable dust sampler).

These suggested improvements reinforce that comprehensive data sharing should be encouraged by authors and requested by reviewers, for example, through the use of supplementary material. The limitations identified and suggested improvements can be overcome by this comprehensive data sharing which will allow better communication within the community. This improved communication can ultimately also allow technology improvements for workplace sampling.

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