

CALIBRATION OF PHOTOMETER-BASED DIRECT-READING AEROSOL MONITORS

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All photometer-based direct-reading aerosol monitors use the principle of the light scattering to determine airborne particle concentration. Most photometers are calibrated in the factory using a „standard test dust” and are adjusted to agree with respirable dust concentration measurements made using reference gravimetric methods. In practice, it is highly unlikely that the „standard” test dust will exhibit the same physical properties (refractive index, density, particle size distribution, shape) as the airborne particles being measured. In order to obtain an accurate measure of airborne particle concentration, the aerosol monitor should always be compared to a reference gravimetric dust sampler placed alongside and adjusted accordingly. This study conducted controlled experiments to compare the measurements of real-time time photometers with gravimetric mass. Particulate matter source tested was wood-dust generated by handheld sanding operation.

KEYWORDS

photometer, correction factor, airborne particle concentration,
gravimetric reference, sampling system

1 INTRODUCTION

The photometer is a device that produces an electrical signal that varies with the intensity of scattered light received from a particle or an ensemble of particles in the interrogation volume region [Wang 2011]. A laser or emitting diode is used to produce a high intensity source of light, which is usually in the visible near-infrared spectrum. This is collimated and illuminates airborne particles entering the sensing volume of the instruments. The amount of light scattered by an airborne particle entering the detector is a complex function of the particle size, shape, refractive index, wavelength of the light source. The instrument optics is usually designed such that the intensity of the light scattered at a particular angle is proportional principally to the respirable fraction of the airborne particle concentration [CEN/TR 16013-3 2012].

Depending on how the aerosol being measured enters the instruments sensing zone, photometer-based direct-reading aerosol monitors can be classified into passive and active. Passive aerosol monitors are generally of an open cell design in which the aerosol to be measured passes into optical sensing zone by the natural movement of the surrounding air. Active

aerosol monitors draw the aerosol through an inlet nozzle and into the sensing chamber by an in-built pump.

Photometers are generally useful for relative assessment of aerosol concentration variations rather than for measuring absolute aerosol concentration. Their main advantage is that they give an almost instantaneous measure of airborne particle concentration, thereby reducing considerably the time and effort associated with standard gravimetric methods. Photometers are therefore best suited to assess variations of airborne particle concentration in time or space and to check for any sudden change of concentration [CEN/TR 16013-3 2012]. Typical applications are: detection of dust emission sources and their relative magnitudes, detection and relative quantification of concentration peaks due to specific operations, assessment of the effectiveness of dust control systems or background sampling to assess concentration variations and mean concentration during a working shift period.

Photometer-based direct-reading aerosol monitors are not ideal for the measurement of worker exposure or to check whether threshold limit values of industrial dust concentrations are exceeded [CEN/TR 16013-3 2012]. According to [Wang 2011] their main disadvantage is that photometric signal is dependent on particle properties such a size, shape and refractive index, thus requiring different calibration factors for different aerosols. Further, photometers are typically more sensitive to particles having diameters close to wavelength of the light source, with precipitous drop off in signal per unit mass for particle outside of this size range. The photometer needs therefore to be calibrated not only with an aerosol of the same composition, but also with the same particle size distribution, as the aerosol measured. Ultimately, contamination of optics with dust can cause significant zero drift of the instrument.

Most photometers are usually calibrated in the factory using an Arizona Road Dust and are adjusted to agree with respirable dust concentration measurements made using reference gravimetric methods. At the same time as calibrating the aerosol monitor, certain manufacturers also produce an optical reference element. This is usually in the form of an optical filter that is inserted into monitors sampling zone and creates a fixed optical scattering effect. After the aerosol monitor has been calibrated with ARD the calibration element is inserted and the resulting concentration reading is recorded and is supplied with the instrument. This can be used at any time as single point check to confirm the factory calibration for the monitor [CEN/TR 16013-3 2012].

The composition of the aerosol being measured is often unknown but is likely to have different physical properties to the aerosol with which the instrument was originally calibrated in the factory [CEN/TR 16013-3 2012]. Therefore, a separate calibration should be carried out each time the monitor is exposed to a different aerosol. However, if the photometer is to be used to measure relative changes in concentration then separate calibration is not essential. In order to obtain an accurate measure of airborne particle concentration, the aerosol monitor should always be compared to a reference gravimetric dust sampler to determine an average calibration factor for the aerosol measured [Thorpe 2013]. Some active aerosol monitors include an integral back up filter onto which the aerosol passing through the sensing zone is captured, and can be used to determine the reference gravimetric concentration. For aerosol monitors that do not include a backup filter or cannot be fitted with an in-line size-selective adaptor, the only option is to use an external gravimetric sampler.

The aim of the study was to compare the performance of two photometer-based direct-reading aerosol monitors with gravimetric reference sampler positioned alongside, based on determination of the correction factor.

2 MATERIALS AND METHODS

2.1 Aerosol monitors tested

Personal real-time dust monitor HAZ-DUST IV™ (HazDust) uses an internal adjustable pump to introduce aerosol into sampling inlet. It has measurement range of 0,01 mg.m⁻³ – 200 mg.m⁻³ for particle size range 0,1 μm to 100 μm and it is factory calibrated using NIST traceable SAE fine test dust. For the purpose of these measurements, an SKC GS-3 cyclone inlet with adaptor was used so that only respirable size fraction was sampled. Flow rate of internal sampling pump was set to operate at 2,75 L.min⁻¹ using multi-purpose calibration jar.



Figure 1. Personal real-time aerosols monitor HAZ-DUST IV™

The sensing head of hand-held monitor Microdust Pro CEL 712 (Microdust) is detachable cylindrical measurement wand. It is passive monitor that relies on ambient movement of the surrounding air. The dust enters and leaves through a hole in the side of the probe. It has measurement range of 0 mg.m⁻³ to 2 500 mg.m⁻³. The instrument is factory calibrated using a method traceable back to isokinetic techniques using ISO 12103-1 A2 Fine test dust.



Figure 2. Passive aerosols monitor Microdust Pro CEL 712

2.2 Experimental configuration

Comparative measurements were carried out inside homemade dust chamber of dimensions (length x width x

height) 1180 mm x 520 mm x 760mm. The tested dust was produced in laboratory by sanding a plank of beech using an orbital sander (PSS 250 AE, Bosch) fitted with 80 grade sanding paper. The wood dust moisture was determined by gravimetric method and ranged from 8% to 10%. Dust was introduced manually into the chamber through entrance pipe. Dust dispersion inside the chamber was provided by fan. Although the temperature and relative humidity inside the chamber were not regulated, they remained fairly constant between 21–23 °C and 36–37%, respectively, throughout the tests. Air velocity at sampling points was measured using anemometer (Testo 480, Testo), it ranging from 0,17 m.s⁻¹ to 0,2 m.s⁻¹.

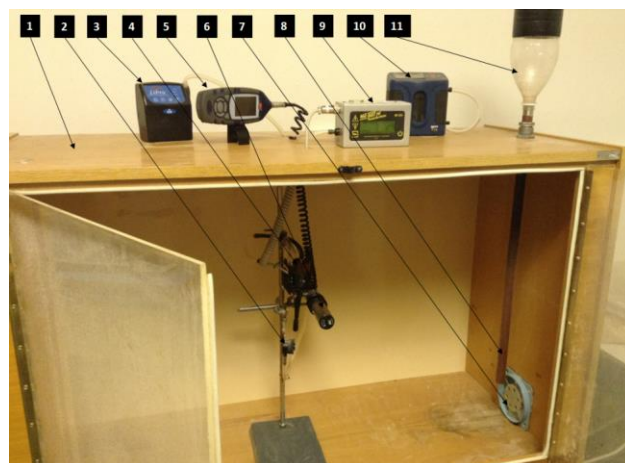


Figure 3. Experimental set-up: 1-dust chamber, 2-IOM sampler, 3-sampling pump, 4-cyclone sampler, 5-Microdust, 6-sampling probe, 7-fan, 8-entrance pipe, 9-HazDust, 10-flow meter, 11-sanding dust hopper

Reference sampler (IOM, SKC Ltd.) was placed in close proximity to measuring probes to ensure that they were exposed to the same concentration of tested aerosol. IOM sampler was loaded with a 25 mm glass microfiber filter without binder (GF 50 025, Albet) and polyurethane foam insert (IOM Multidust sampler, SKC Ltd.). All the filters were conditioned and weighted using microbalance (XA 110, Radwag) before and after exposure. IOM sampler was connected to a pump (L-4, A. P. Buck), which was set to operate at 2 L.min⁻¹ using a primary flow meter (Defender 510, MesaLabs, Butler).



Figure 4. Detail of samplers position

Prior to making measurements the aerosol monitors were zeroed by purging measurement chambers with particle-free air. Optical reference elements were used to perform a single

point check to ensure that the aerosol monitors were adjusted to the factory-set calibration.

In order to determine correction factor (CF), the average photometer reading (C_p) was compared to measurements made with external gravimetric sampler (C_g). Sampling time was 20 minutes in each measurement so that a weighable dust sample was obtained on the filter.

3 RESULTS AND DISCUSSION

The average concentration measured with dust monitors inside the dust chamber was plotted against the reference IOM respirable concentration and these are shown in Fig. 5. The solid black line represents a 1:1 relationship.

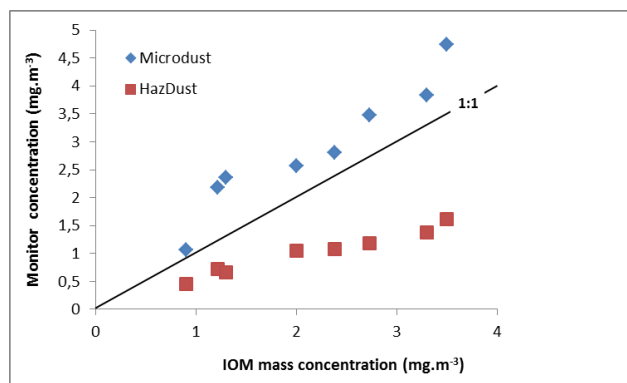


Figure 5. Dust monitors response versus IOM respirable concentration

The results are also summarized in Tab. 1, which shows the mean correction factors for both monitors, coefficient of determination derived from a linear regression of the data, standard deviation (SD) and coefficient of variation (CV), expressed as a percentage.

Dust monitor	Correction factor	No. of readings	Coefficient of Determination	SD	CV (%)
HazDust	2,071	8	0,967	0,2	10,4
Microdust	0,745	8	0,907	0,1	15,6

Table 1. Summary of correction factors for the real-time dust monitors

Both monitors showed good linearity when compared with reference IOM respirable concentration, indicated by high coefficient of determination values. On average, HazDust monitor underestimated the respirable concentration by 47% compared with reference sampler, which could be caused by different sampling efficiency of IOM sampler with polyurethane foam insert and GS-3 cyclone.

On contrary, Microdust monitor consistently read higher than HazDust, overestimating the measurements of respirable concentration by 33% compared with reference sampler. This is because Microdust was factory calibrated against the concentration of total suspended particulate, which approximates to the inhalable concentration.

There have been various studies on determining correction factors for numerous photometer-type dust monitors, e. g. [Baltrenas 2005, Thorpe 2007, Cavlovic 2009, Santi 2010, Fujimoto 2010, Thorpe 2013, Lukacova 2014, Rasulov 2016]. Inside a calm air chamber [Thorpe 2007] investigated performance of Microdust monitor with two size-selective adaptors: the Higgins-Dewell cyclone adaptor and the conical inhalable sampler adaptor with porous foam inserts. The response of the Microdust was found to be linear with respirable dust concentration when operated either passively or actively using the cyclone size-selective inlets. Its response to

beech wood dust was, however, lower when operated actively with cyclone adaptor compared to the passive operation and lower still when used with the porous foam filter. [Cavlovic 2009] evaluated reliability and applicability of photometric methods in determining mass concentration of wood dust in the woodworking environment in comparison to gravimetric method. They collected samples of inhalable wood dust in several plants during machining, among other, wet and dry beech-wood by Split 2 monitor (SKC Ltd). Results of their study showed that lower exposure to airborne particles from the same sample is determined by continuous photometry unit, than by gravimetric method with IOM sampler of inhalable particle fraction. [Thorpe 2013] carried out laboratory and field measurements to investigate how currently available photometer direct-reading dust monitors behave when they are used to determine the concentration of airborne inhalable dust. Laboratory results showed that the photometer-type dust monitors observed poor linearity for all types of tested dust. In addition, photometer responses varied considerably with changing particle size, which resulted in appreciable errors in airborne inhalable dust concentration measurements. Similar trends were also observed during field trials.

Comparing results of dust monitors evaluation from different experimental setups and field measurements reported in the literature is difficult. However, results of our study confirmed that determining of correction factor should be an essential part of any aerosol photometer using.

There are some limitations inherent to this study. One limitation of this study is that we did not conduct the experimental trials using Microdust without the polyurethane foam filter respirable sampling adapter. In order to compare sampler/dust monitor performance, it is important that air velocity and dust concentration within the sampling region are constant and uniform [Thorpe 2013]. Because dust was introduced manually into the chamber, the dust concentration was changed with time inside the chamber. A minor limitation of this study is that we did not analyze the potential effect of temperature and relative humidity of air inside chamber on performance of samplers. Despite of these limitations, the presented results provided further information as regard to the performance of photometer-based direct-reading aerosol monitors in measuring wood dust concentration.

4 CONCLUSIONS

This study conducted controlled experiments to compare the measurements of real-time time photometers with gravimetric mass. Particulate matter source tested was wood-dust generated by handheld sanding operation. The response of both monitors was found to be linear with respirable dust concentration. Tests carried out inside dust chamber showed that Microdust consistently read higher than HazDust.

This study emphasizes the importance of photometer-type dust monitors calibration. The type of calibration depends on the type of measurement being made. In order to obtain an accurate measure of airborne particle concentration, the aerosol monitor should always be compared to a reference gravimetric dust sampler placed alongside and adjusted accordingly. Unless they are properly calibrated for the aerosol being measured, photometers can significantly overestimate or underestimate the "true" concentration of the respirable fraction of aerosol. In addition, changes in particle size during calibration means that the use of an "average" calibration factor can also result in errors in the corrected photometer measurement results [CEN/TR 16013-3 2012].

Concise expression of measurement uncertainty is quite challenging. We propose here that a total measurement

uncertainty should be estimated as a function of the instrument (calibration) uncertainty and the field uncertainty. In practice, an important first establishment of uncertainties is done when calibrating an instrument. However, characterization of uncertainties during calibration is performed under ideal conditions. It is practically impossible to completely address all the sources of uncertainties of the measurement in an operational context. Instrument response time and sampling period, as well as the temporal change in environmental conditions, measurement setup, and maintenance, can affect the representativeness of a measurement in the field. Therefore, one should not expect that a calibration of the instrument will provide the total uncertainty for the operational measurements in the field. Our further work will focus on investigation of parameters (e.g. dust from different wood species, sampling time) that influence the size of correction factor.

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REFERENCES

- [Baltrenas 2005] Baltrenas, P. and M. Kvasaukas. Experimental investigation of particle concentration using mass and optical methods. *Journal of Environmental Engineering and Landscape Management*, 2005, Vol. 13, No. 2, pp 57-64.
- [Cavlovic 2009] Cavlovic, A. et al. Correction factor for real-time determination of wood dust mass concentration by photometric method. *Drvna industrija*, 2009, Vol. 60, No. 1, pp 33-42.
- [CEN/TR 16013-3 2012] CEN/TR 16013-3:2012. Workplace exposure. Guide for the use of direct-reading instruments for aerosol monitoring. Part 3: Evaluation of airborne particle concentrations using photometers.
- [Fujimoto 2010] Fujimoto, K. et al. Difference in mass concentration of airborne dust during circular sawing of five wood-based materials. *Journal of Wood Science*, 2011, Vol. 57, Issue 2, pp 149-154.
- [Lukacova 2014] Lukacova, K. et al. Possibilities of utilization of equipment using IR principle for monitoring solid aerosols in real conditions. In: *Proceedings from SGEM, Albena*, 17-26 June, 2014. Sofia: STEF92 Technology, pp 515-518. ISBN 978-619-7105-17-9

[Rasulov 2016] Rasulov, O. and Schwarz, M. Monitoring the air pollution and evaluation of the impact of aluminium in Talco. *Journal of Environmental Management and Tourism*, 2016, Vol. 7, No. 2, pp 169-174.

[Santi 2010] Santi, E. et al. Real-time aerosol photometer and optical particle counter comparison. *Nuovo Cimento della Societa Italiana di Fisica B*, 2010, Vol. 125, No. 8, pp 969-981.

[Thorpe 2007] Thorpe, A. and Walsh, P. T. Comparison of Portable, Real-Time Dust Monitors Sampling Actively, with Size-Selective Adaptors, and Passively. *Annals of Occupational Hygiene*, 2007, Vol. 51, No. 8, pp 679-691.

[Thorpe 2013] Thorpe, A. and Walsh, P. T. Direct-Reading Inhalable Dust Monitoring – An Assessment of Current Measurement Methods. *Annals of Occupational Hygiene*, 2013, Vol. 57, No. 7, pp 824-841.

[Wang 2011] Wang, X. et al. Size segregated aerosol mass concentration measurement device. US Patent No.: US 7,932,490 B2, Apr. 26, 2011.

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