SIST

SLOVENSKI STANDARD
SIST-TP CEN/TR 16013-3:2012

01-december-2012

Izpostavljenost na delovnem mestu - Vodilo za uporabo instrumentov z neposrednim odčitavanjem za monitoring aerosolov - 3. del: Vrednotenje koncentracij lebdečih delcev s fotometri

Workplace exposure - Guide for the use of direct-reading instruments for aerosol monitoring - Part 3: Evaluation of airborne particle concentrations using photometers

Exposition am Arbeitsplatz - Leitfaden für die Anwendung direkt anzeigender Geräte zur Überwachung von Aerosolen - Teil 3: Ermittlung der Konzentrationen luftgetragener Partikel mit Photometern

Exposition au poste de travail - Guide d'utilisation des instruments à lecture directe pour la surveillance des aérosols - Partie 3 : Évaluation des concentrations de particules en suspension dans l'air à l'aide de photomètres

Ta slovenski standard je istoveten z: **CEN/TR 16013-3:2012**

ICS:

13.040.30	Kakovost zraka na delovnem mestu	Workplace atmospheres

SIST-TP CEN/TR 16013-3:2012 **en**

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CEN/TR 16013-3

October 2012

ICS 13.040.30

English Version

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This Technical Report was approved by CEN on 10 June 2012. It has been drawn up by the Technical Committee CEN/TC 137.

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Ref. No. CEN/TR 16013-3:2012: E

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Foreword

This document (CEN/TR 16013-3:2012) has been prepared by Technical Committee CEN/TC 137 "Assessment of workplace exposure to chemical and biological agents", the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

CEN/TR 16013 consists of the following parts, under the general title *Workplace exposure — Guide for the use of direct-reading instruments for aerosol monitoring*:

— *Part 1: Choice of monitor for specific applications*;

— *Part 2: Evaluation of airborne particle concentrations using Optical Particle Counters*;

— *Part 3: Evaluation of airborne particle concentrations using photometers*.

Introduction

All photometer-based direct-reading aerosol monitors use the principle of light scattering to determine airborne particle concentration. Here, a light source (usually produced by a laser or diode) is collimated and illuminates airborne particles entering a sensing volume. The instrument optics are 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. Other physical properties of the aerosol such as particle size, refractive index and particle shape, will affect their response by varying degrees (see [7]) although this can be minimised by careful design of the photometer. Therefore, 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. 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. They are also better at measuring aerosols with high vapour pressures that would normally evaporate during standard gravimetric analysis. Some instruments include a pre-classifier on the inlet (cyclone or impactor) to make the overall response closer to the respirable dust definition.

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. Typical applications are:

— walk-through surveys;

— background sampling to assess concentration variations and mean concentration during a working shift period;

— assessment of the effectiveness of dust control systems;

— measurement of indoor air quality;

— as part of exposure video visualization systems.

For measurement of personal exposure they should be considered as complementary to conventional filter-based gravimetric methods (see [2]), although with careful calibration, they can also give an accurate measure of respirable dust exposure, i.e. that which enters the mouth and nose and passes to the lower regions of the respiratory system (see EN 481).

1 Scope

This Technical Report describes the use of photometers for the determination of airborne particles belonging to the respirable fraction and gives details on their limitations and possible uses in the field of occupational hygiene.

NOTE Photometers can also be used to detect other size fractions of airborne particles after aerodynamic pre-separation, but these are not the focus of this Technical Report.

The method complements existing conventional long-term aerosol particle sampling and can be used for:

- instantaneous (direct-reading) measurement,
- time-related monitoring,
- investigation of space-related aerosol evolution (mapping), and
- exposure visualization.

The method enables e.g.:

- detection and relative quantification of concentration peaks due to specific operations (bagging, sanding, etc.);
- identification of most exposed workers with a view to more detailed studies of risks and prevention measures to be applied; and
- detection of dust emission sources and their relative magnitudes.

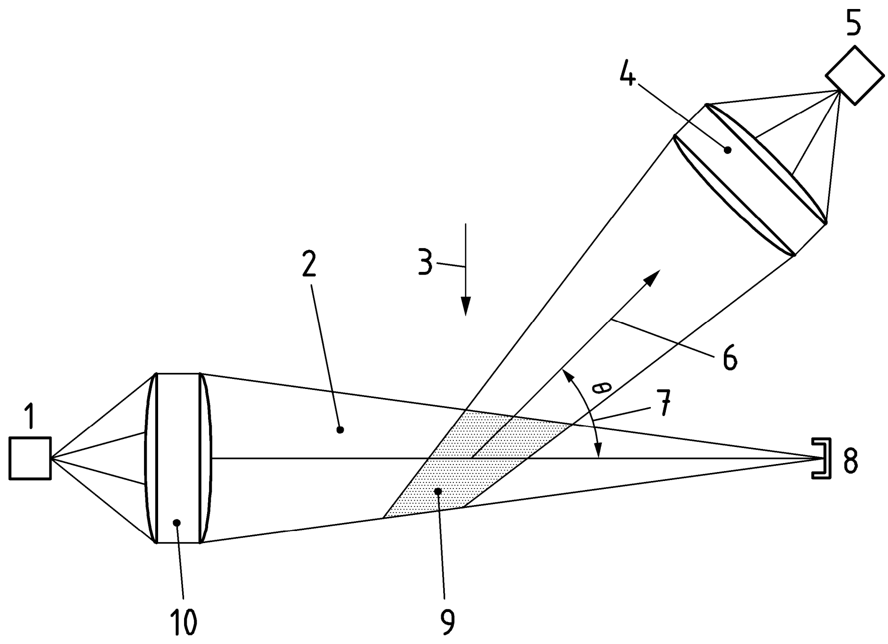
2 Operating Principle

2.1 General

A laser or light 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 instrument. The optical sensing volume is created by intersection of illuminating and detecting light beams as shown in Figure 1. The intensity of the light scattered at a particular angle is proportional to the airborne particle concentration and is detected using sensitive photomultipliers or photodiodes with response spectra covering approximately the source emission spectra.

2.2 Light scattering

Interaction of a light beam with an airborne particle in suspension can cause several effects: absorption of part of the light, reflection, refraction or diffraction of the beam. These combined effects result in scattering of the incident light in every direction. The illumination and collection optics are arranged inside a photometer so that light scattered at a fixed range of angles reaches the detector (see Figure 1). Depending on the design, these instruments can measure the scattered light in the region of $\theta = 90^\circ$, 45° or less than 30°. Choice of observation angle plays a prominent part in detection. Front scattering is relatively insensitive to changing airborne particle refractive index and so forward-scattering photometers with scattering angles $< 30^\circ$ are less sensitive to the refractive index of the aerosol than instruments with a 90° scattering angle. However, at small scattering angles, photometers overestimate particles smaller than 1,5 µm.



Key

1 light source

2 incident light

3 aerosol flow

4 lens

5 light detector

6 scattered light

7 scattering angle

8 light stop

9 sensing volume

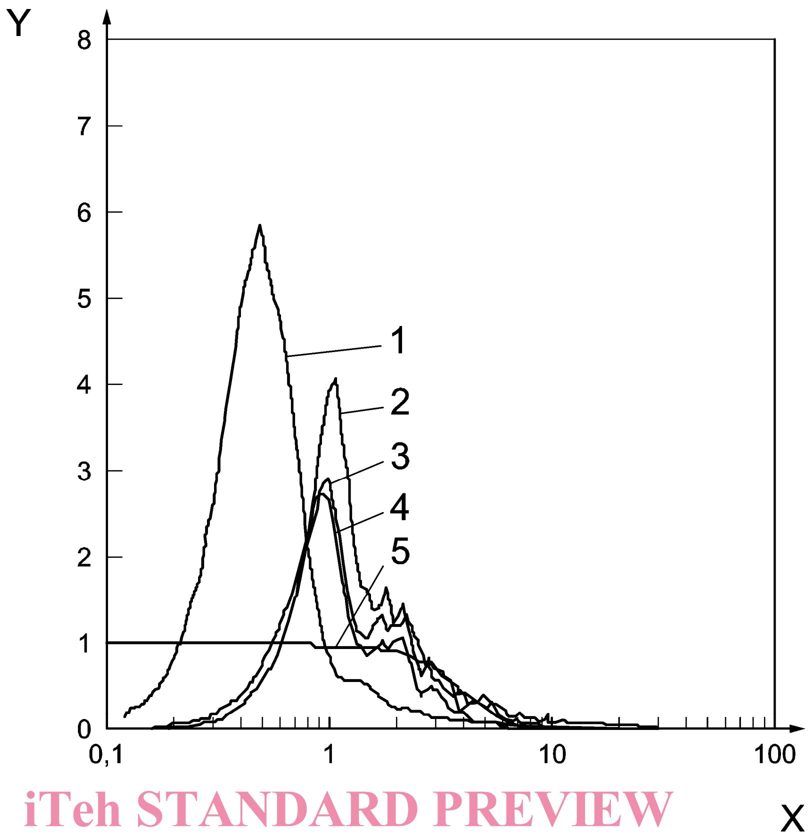
10 lens

Figure 1 — Light scattering aerosol photometer

2.3 Instrument response — Effects of airborne particle properties

2.3.1 General

For spherical particles of known refractive index the instrument response can be calculated by applying Mie's light scattering theory (see [13]). The calculated response for a typical light scattering photometer is shown in Figure 2.



Key

X particle diameter, in micrometres (µm)

Y calculated relative response at constant mass concentration

1 coal dust

2 fused alumina

3 quartz

4 Arizona Road Dust

5 sampling convention for the respirable fraction

Figure 2 — Calculated size-dependent mass-sensitivity of a photometer for four dust materials along with the conventional respirability (see EN 481)

The physical parameters of some aerosols measured are listed in Table A.1. The photometer parameters are as follows:

— wavelength of incident light λ = 950 nm;

— angle of detection of scattered light $\theta = 70^{\circ}$;

— semi-angle of light collection $\beta = 10^{\circ}$.

Careful design of the photometer (observation angle, wavelength of the incident light etc., see [1]) allows measurement of a certain particle size fraction of aerosol. Figure 2 shows a photometer-based dust monitor that is essentially responsive to particle sizes within the respirable fraction of aerosol. In this case, the photometer response increases up to a particle diameter of about 1 µm. This is followed by a decrease in response for larger particles with a large drop in response for particles greater than 10 µm.

In reality 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 and will therefore change for different dust types. It also depends on the geometry of the photo-detecting optical system.

2.3.2 Particle density

The density of an airborne particle does not affect its light scattering properties and so a photometer's response will not change with the density of the aerosol being measured. However, the mass concentration of an aerosol does depend on the particle density and so concentration measurements made by the photometer should be corrected for the difference between the densities of the actual dust measured (ρ_{act}) relative to that of the calibration dust (ρ_{cal}) (see 4.2), assuming that the density of the actual dust is known. To make the correction, the ratio of the two densities, ρ_{act}/ρ_{cal} is applied to the photometer measurement (see [15]). Care should be taken when applying a simple density correction factor since any changes in density (caused by a change of aerosol type) will most likely be accompanied by changes in the particle size distribution and refractive index of the aerosol being measured, which will affect the monitor response (see 2.3.3 and 2.3.4).

2.3.3 Particle size

Photometer response is strongly dependent on particle size (see [18] and [22]). For airborne particles, smaller than the wavelength of the illuminating light, the intensity of the scattered light is proportional to d_p^6, where d_p is the particle diameter. For larger particles, typically greater than the wavelength of the illuminating light, the intensity of the scattered light is approximately proportional to d_p^2. In the intermediate region where the particle size approximates to the wavelength of the illuminating light the intensity function can undergo oscillations, depending on the optical properties of the airborne particles (see Figure 2).

2.3.4 Particle refractive index

Changes in refractive index produce a non-linear change in photometer response. Therefore, a correction factor based on a simple ratio of the refractive indices of the aerosol being measured to the aerosol with which the photometer was originally calibrated cannot be applied. However, there is evidence to suggest that the majority of airborne particles has a refractive index very near to 1,5 (see [7] and [12]). Furthermore, most modern photometers measure forward-scattered light (sensing angle of 45° to 95°), which is less sensitive to changes in refractive index (see [16]). Therefore, any small difference between the refractive index of the measured aerosol relative to the calibration aerosol can either be ignored or considered linear over that narrow range and compensated for by a linear correction factor. For airborne particles with a refractive index substantially different from 1,5 the effects on photometer response are largely unknown, but a photometer can anyhow be recalibrated for particles with a constant refractive index.

2.3.5 Particle shape

Theoretical and experimental calibration curves of optical techniques for particle characterisation are usually confined to airborne particles of spherical shape, whereas most aerosol systems consist mainly of particles having irregular shape. The Mie scattering patterns of a non-spherical object can differ considerably from those of the sphere, especially when particle size is much larger than the wavelength of the scattered light. The effects of particle shape on instrument response can be reduced by collecting scattered light produced by diffraction alone. Therefore, monitors that measure scattered light at small sensing angles (< 30°) i.e. in the front diffraction lobe will be less sensitive to changes in particle shape.

3 Instrument types

3.1 General

There are many photometer-based direct-reading aerosol monitors available from a number of manufacturers. They are available in various sizes and weights, which will determine their most appropriate area of application:

- small and lightweight for personal monitoring;
- portable for workplace surveys/mapping;
- bench mounted for static monitoring.

Photometer-based direct-reading aerosol monitors measure light scattering intensities that generally correspond to aerosol concentrations from as low as 1 µg/m^3 up to several hundred mg/m^3 and often display basic statistical information such as average, maximum and minimum concentration. Most incorporate data logging facilities where measurements of concentration are stored inside the instrument's internal memory. These measurements can be downloaded to a computer later on for detailed interpretation of the data. Many photometers also have alarm set-points such that when the concentration exceeds a pre-programmed value, an alarm is triggered thereby alerting the user.

Photometers can be classified into two distinct types depending on how the aerosol being measured enters the instrument's sensing zone. The first is known as a “passive” aerosol monitor whereby airborne dust enters the instrument by the natural air movement in the surrounding air (see 3.2). The second is known as an “active” aerosol monitor whereby air is drawn into the sensing zone by an in-built pump (see 3.3).

A list of photometer-type aerosol monitors that are currently available is given in Annex B. This list does not claim to be an exhaustive one, but it includes many of the types that are widely available and that are battery-powered and therefore suitable for use in occupational settings.

3.2 Passive aerosol monitors

Passive aerosol monitors are generally of an open cell design in which the aerosol to be measured passes into the optical sensing zone by the natural movement of the surrounding air. This means that they can under-sample in low wind conditions where a proportion of the aerosol does not enter the instrument. In personal sampling the movement of the worker will cause the airborne particles to enter the optical sensor cell, and this is therefore not a problem. But it could be a problem for static sampling, however in these situations there is usually air movement which will transport airborne particles into the sensing volume. A modulated infrared monochromatic light source is often used to limit the influence of stray ambient light entering the open cell, which is absorbed by a filter placed in front of the photodetector (see [3]).

Passive aerosol monitors can be susceptible to contamination of the optics with dust, because of the open cell design. This can lead to a significant increase in the monitors “zero reading” throughout a measurement, especially where the concentration of aerosol is high.

3.3 Active aerosol monitors

Active aerosol monitors draw the aerosol through an inlet nozzle and into the sensing chamber using an in-built pump. These monitors sometimes utilise a sheath flow of air that isolates the aerosol in the chamber to help keep the optics clean for improved reliability and lower maintenance (these are identified in Table B.1). Some monitors also collect the airborne particles exiting the chamber onto an internal filter for subsequent gravimetric or chemical analysis.

3.4 Size-selective aerosol monitors

A number of active aerosol monitors can be fitted with size-selective inlets that separate the aerosol into the various health-related fractions prior to entering the instrument (see Table B.1). Examples of this type of aerosol monitor are the TSI Sidepak™ and TSI Dustrak™[1)] monitors that use impactor or cyclone adaptors to separate the aerosol into $PM_{1,0}$, $PM_{2,5}$, PM_{10} and respirable size fractions prior to entering the instrument's sensing zone.

Some passive aerosol monitors can also be made to operate actively (see Table B.1) by drawing air through a size-selective adaptor located on the inlet of the monitor, using a small personal sampling pump. The adaptor usually consists of a personal cyclone or inlet containing size-selective porous foams that allow only respirable-sized airborne particles to enter. The adaptors can be used together with a filter to capture the particles passing through the monitor inlet, allowing a concurrent in-line gravimetric calibration to be carried out (see 4.4.2). The adaptors also ensure that the aerosol monitor is only ever challenged with respirable-sized airborne particles so

1) TSI Sidepak™ and TSI Dustrak™ are examples of suitable products available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by CEN of these products.