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Izpostavljenost na delovnem mestu - Vodilo za uporabo instrumentov z neposrednim odčitavanjem za monitoring aerosolov - 2. del: Vrednotenje koncentracije lebdečih delcev z uporabo optičnih števcev delcev

Workplace exposure - Guide for the use of direct-reading instruments for aerosol monitoring - Part 2: Evaluating airborne particle concentrations using Optical Particle Counters

Exposition am Arbeitsplatz - Leitfaden für die Anwendung direkt anzeigender Geräte zur Überwachung von Aerosolen - Teil 2: Ermittlung der Konzentration Luft getragener Partikel mit optischen Partikelzählern

Exposition au poste de travail - Guide d'utilisation des instruments à lecture directe pour la surveillance des aérosols - Partie 2 : Evaluation des concentrations de particules en suspension dans l'air à l'aide de compteurs optiques de particules

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Management Centre: Avenue Marnix 17, B-1000 Brussels

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Foreword

This document (CEN/TR 16013-2:2010) 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.

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

— *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* (in preparation)

Introduction

Optical Particle Counters (OPC) count airborne particles and are therefore suitable for measuring concentrations expressed in number of particles per unit volume of air. Counting-based measurement of mass concentration and particle size estimation is indirect: a number of assumptions and approximations are made to access the information sought. Nevertheless, optical particle counters can be used to evaluate the efficiency of preventive actions and to monitor the spatial distribution and/or the temporal evolution of an aerosol. In occupational hygiene, no standard recommends workers' exposure assessment using optical particle counters. These instruments should instead be considered as permitting a complementary approach to the conventional filter-based gravimetric method. A confirmation of OPC mass concentration by a conventional sampling method with a calibrated instrument is recommended when comparing concentration measurements with legal limit values.

An OPC method allows assessment of working place aerosol conditions including:

- almost instantaneous evaluation of particle concentration and size distribution;
- estimating concentration variations and mean concentration of aerosol particles during a working shift period;
- sampling to constitute a particle sample for further analysis (when equipped with terminal filter).

1 Scope

This Technical Report describes the principle underlying evaluation of one or more health related aerosol fractions using an optical particle counter and details its limits and possibilities in the field of occupational hygiene.

The method complements conventional long-term aerosol particle sampling and offers possibilities of:

- instantaneous (direct reading) measurement;
- time-related monitoring;
- investigation of space-related aerosol evolution (mapping);
- assessment of particle size distribution.

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;
- detection of dust emission sources and their relative magnitudes.

Basically, OPCs count airborne particles and are therefore suitable for measuring concentrations expressed in number of particles per unit volume of air. The applicability of the method is limited by the particle size and concentration ranges of OPC instruments, usually approximately 10^{-1} µm to 10^{1} µm and 10^{0} particles/cm^3 to 10^3 particles/cm^3, respectively.

Depending on specific conditions, the OPC method allows filter collection of an aerosol fraction, in the best case close to a health-related fraction (see EN 481), provided the OPC has the relevant sampling efficiency over its optical particle size range. If this is not the case, at least a sufficient aspiration efficiency is required to cover the size range of particles which can be detected and measured by the OPC optical system.

Converting count-based particle number concentrations into mass concentrations based on estimated particle size is indirect and therefore the accuracy of the conversion is limited by several simplifying assumptions:

- identical optical parameters for both the calibration aerosol and the measured workplace aerosol;
- all counted particles of the workplace aerosol are spherical with a geometric diameter equal to the determined optical diameter and with identical density;
- the aspiration and transmission efficiencies of the OPC are known or estimated from engineering models.

Therefore confirmation of the estimated mass concentrations from OPC particle size distributions by a conventional sampling method is necessary (see [3]). The estimated mass concentrations from OPC data are only indicative and cannot be used for a direct comparison with a legally enforced occupational exposure limit.

2 Principles of the method

2.1 Light scattering

An aerosol particle scatters light energy through the effects of reflection, refraction absorption, and diffraction. The amount of energy scattered can be calculated by applying Mie's theory (see [8]), which can be summarised by the following simplified equation for a non-polarised monochromatic incident light beam and a spherical particle:

$$I = I_0 \frac{1}{8\pi^2} \frac{\lambda^2}{r^2} \left[i_1(\alpha,n,\theta) + i_2(\alpha,n,\theta) \right] \tag{1}$$

where

I is the intensity of light scattered at angle θ, per unit cross-sectional area, in watts per square metre;

I_0 is the intensity of the incident beam, per unit cross-sectional area, in watts per square metre;

α is the particle size parameter, where $\alpha = \pi \times D/\lambda$ and D is the spherical particle diameter, in micrometres;

n is the particle complex refraction index;

λ is the wavelength of incident light, in micrometres;

r is the distance from the centre of the scattering particle to the point where the intensity, I, is measured, in micrometres;

θ is the scattering angle;

i_1, i_2 are Mie intensity functions.

The particle diameter D can be deduced from Equation (1) by measuring the intensity of light scattered, when the particle optical parameters and the incident light beam characteristics are known.

2.2 Working principle

OPCs are closed optical cell instruments featuring an aerosol aspiration system. They are characterised by their very low optical measuring volume (of the order of 1 mm^3) and by a flow rate often of the order of 1 l/min (see [9]). This allows particles to be drawn individually into the sensing zone and recording of the light scattered by each particle. Discrete pulses are counted and their size measured.

The aerosol to be investigated is aspirated through the instrument sampling probe by a constant flow pump. Particles pass one by one into the optical cell, where each particle is illuminated by a focused light beam of specified characteristics and scatters this light according to its properties (complex refraction index, size, shape).

Particles move perpendicularly to the plane formed by the focused light incident beam and the scattered light reception beam. Optical parts are swept by filtered air to prevent any particle deposition inside the optical cell.

The scattered light is focused onto a photo detector and recorded as a pulse. From the pulse size, the particle size is inferred assuming spherical particles. A quantity of signals during predefined integration time can be converted into mass concentration, usually after calibration using the investigated aerosol.

3 OPC performance characteristics

OPC performance characteristics vary according to the aerosol particle sampling efficiency of the sampling head, the type of light used (monochromatic or polychromatic), its intensity (incandescent or laser lamp), the cell optical arrangement (choice of scattering axis, width of reception solid angle), the sensitivity of the photosensitive component (photodiode, photomultiplier) and the electronic discriminating power (pulse frequency and pulse size measurement).

The limited flow rate, often of the order of 1 l/min, restricts the chances of attaining aerodynamic conditions favourable to good aspiration orifice efficiency and ensuring full transmission of particles to the optical cell. OPC flow rate system characteristics (aspiration orifice and tube geometries, air velocities and flow rates) are such that particle losses are mainly inertial and therefore greater for larger particles (especially those larger than 10 µm).

Maximum concentration that can be measured by an OPC is limited to a few thousand particles per cubic centimetre to avoid coincidence error by passing several particles simultaneously through the optical sensing volume.

4 Number and mass concentrations

OPC counting for a time t, in minutes, gives the number N of particles, counted and classified by size in different channels.

Knowing the airflow Q aspirated by the OPC, it is simple to calculate the particle number concentration in terms of number of particles per unit volume of air C_N:

$$C_{\mathrm{N}} = 0,001 \frac{N}{Q \times t} \tag{2}$$

where

C_{N} is the particle number concentration in terms of number of particles per unit volume of air, in 1/cm^3;

N is the number of particles counted;

Q is the airflow aspirated by the OPC, in litres per minute;

t is the time, in minutes.

Mass concentration C_{m} is expressed in particle mass per unit volume of air. Based on the assumption that particles are spherical and identify the particle geometrical diameter as its optical diameter, the mass of a particle classified in channel i, m_i can be calculated from the equation:

$$m_i = \frac{10^{-12}}{6} \pi D_i^{\,3} \rho \tag{3}$$

where

m_i is the mass of a particle classified in channel i, in milligrams;

D_i is the mean diameter between channel i left-hand and right-hand thresholds, in micrometres, as selected by the manufacturer or specified by the user;

ρ is the particle density, in kilograms per cubic metre.

The mass of all particles counted by the OPC is:

$$m = \sum_i m_i \; N_i \tag{4}$$

where

m is the mass of all particles counted by the OPC, in milligrams;

$m_i \, N_i$ is the mass of particles classified in channel i.

The mass concentration of the sampled aerosol C_m is given by the equation:

$$C_\text{m} = 1\,000 \frac{m}{Q \times t} \tag{5}$$

where

C_m is the mass concentration expressed in particle mass per unit volume of air, in milligrams per cubic metre.

NOTE Light scattering parameters are not those characterising aerosol mass concentration. The light scattering response is dependent on the index of refraction of particles, and not on their density. On the other hand, particle mass concentration depends on particle density, and not on the index of refraction. There is no known physical link between these two properties of matter. This problem should be minimised by an appropriate calibration, but it assumes a fair stability of particle composition and size distribution on the site, even when aerosol concentration changes, see [4].

5 Mass concentrations of thoracic and respirable aerosol fractions

The dichotomous model of aerosol fractioning as it progresses though the respiratory tract enables us to calculate the thoracic fraction concentration C_T or the respirable fraction concentration C_R from the total airborne particle concentration C_m using the penetration probabilities given in EN 481.

For the thoracic fraction:

$$C_\text{T} = C_\text{m} \int P_\text{I}\,(D_\text{ae})\; P_\text{T}\;(D_\text{ae})\; F_\text{m}\;(D_\text{ae})\; dD_\text{ae} \tag{6}$$

For the respirable fraction:

$$C_\text{R} = C_\text{m} \int P_\text{I}\,(D_\text{ae})\; P_\text{R}\;(D_\text{ae})\; F_\text{m}\;(D_\text{ae})\; dD_\text{ae} \tag{7}$$

where

C_T is the thoracic fraction concentration, in milligrams per cubic metre;

C_R is the respirable fraction concentration, in milligrams per cubic metre;

$P_\text{I}(D_\text{ae})$ is the inhalable sampling convention (expressed as a fraction instead of a percentage), as defined in EN 481;

$P_\text{T}(D_\text{ae})$ is the thoracic sampling convention (expressed as a fraction instead of a percentage), as defined in EN 481;