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Workplace atmospheres — Characterization of ultrafine aerosols/nanoaerosols — Determination of the size distribution and number concentration using differential electrical mobility analysing systems

Air des lieux de travail — Caractérisation des aérosols ultrafins/nanoaérosols — Détermination de la distribution granulométrique et de la concentration en nombre à l'aide de systèmes d'analyse différentielle de mobilité électrique

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 28439 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 137, *Assessment of workplace exposure to chemical and biological agents*, in collaboration with Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 2, *Workplace atmospheres*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Introduction

Within occupational hygiene, aerosol concentrations have been traditionally measured in terms of mass concentrations. For some ultrafine aerosols and nanoaerosols, other exposure metrics such as the number and surface area concentration are likely to become important for predicting health effects, depending on chemical and physical properties. This International Standard provides a method for determining the number concentration and size distribution of ultrafine aerosols and nanoaerosols at workplaces by using differential mobility analysing systems (DMASs). This can be used by occupational hygienists and researchers to measure the concentration at some workplaces. The system is generally not suitable for personal exposure measurements.

Workplace atmospheres — Characterization of ultrafine aerosols/nanoaerosols — Determination of the size distribution and number concentration using differential electrical mobility analysing systems

1 Scope

This International Standard provides guidelines for the determination of the number concentration and size distribution of ultrafine aerosols and nanoaerosols by use of mobility particle sizers (also called differential mobility analysers). Only the particle fraction of the aerosol is considered. For ultrafine aerosols and nanoaerosols, exposure metrics such as the number and surface area concentration are important.

This International Standard also gives guidelines for the determination of workplace exposure to ultrafine aerosols and nanoaerosols.

Specifically, the differential mobility analysing system (DMAS), now available from several vendors, is discussed. Principles of operation, problems of sampling in the workplace environment, calibration, equipment maintenance, measurement uncertainty, and reporting of measurement results are covered.

Potential problems and limitations are described, which need to be addressed when limit values are fixed and compliance measurements carried out.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 27628, *Workplace atmospheres — Ultrafine, nanoparticle and nano-structured aerosols — Inhalation exposure characterization and assessment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 27628 and the following apply.

3.1
critical electrical mobility
Z_{crit}
electrical mobility of particles that in the differential electrical mobility classifier are transferred from the sample air flow to the exiting monodisperse aerosol flow

NOTE Due to the finiteness of the DEMC, the exiting monodisperse flow is not strictly monodisperse, but corresponds to a range of electrical mobilities for each voltage.

3.2
particle charge equilibrium
charging condition for aerosol particles that is stable after exposure to positive and negative ions for a sufficiently long period of time

NOTE 1 Bipolar ions are produced by either a radioactive source or a corona discharge.

NOTE 2 The electrical charge on individual particles of an aerosol at charge equilibrium is not neutral.

NOTE 3 Adapted from ISO 15900:2009[1], 2.11.

3.3
(equivalent) particle electrical mobility diameter
diameter of a sphere with the same electrical mobility as the particle in question

4 Symbols and abbreviated terms

4.1 Symbols

B	particle mechanical mobility	s/kg
C	Cunningham correction factor	1
C_{N}	aerosol number concentration	1/m^3
d	particle diameter	nm
d_{p}	equivalent particle electrical mobility diameter	m
$\bar{d}_{\mathrm{p}}$	average equivalent particle electrical mobility diameter	m
D	particle diffusion coefficient	m^2/s
e	basic unit of charge (elementary charge)	$1{,}602\ 177 \times 10^{-19}$ C
q_1	DEMC sample air flow rate	m^3/s
q_2	DEMC filtered sheath air flow rate	m^3/s
q_3	DEMC excess air flow rate	m^3/s
q_4	DEMC exiting air flow rate to particle detector	m^3/s
k	Boltzmann constant	$1{,}38 \times 10^{-23}$ N·m/K
L	length of sampling line	m
n	number of charges	1
p	penetration through sampling line	1
t	(coagulation) time	s
t_{scan}	scan time	s
T	absolute temperature at which the DEMC is operated	K
V_{v}	volume of buffer vessel for the sample air flow rate	m^3
Z	electrical mobility of a charged airborne particle	m^2/V·s
Z_{crit}	critical electrical mobility of a charged airborne particle	m^2/V·s
η	gas viscosity	Pa·s
μ	parameter for diffusion losses	1

4.2 Abbreviated terms

CNC condensation nuclei counter

CPC condensation particle counter

DEMC differential electrical mobility classifier

DMAS differential mobility analysing system

NOTE A DMAS is also known as a differential mobility particle sizer (DMPS) or scanning mobility particle sizer (SMPS).

HEPA high efficiency particle arrestor

5 Principle

The aerosol is sampled in the workplace at a position representative of the atmosphere to which a worker might be exposed. Larger particles than approximately 1 µm are precipitated and the particles smaller than approximately 1 µm drawn into the instrument. After charge conditioning, the aerosol particles are separated in the electrical field of the DEMC (see References [6] and [7]) according to their electrical mobility, which is given by Equation (1).

$$\left.\begin{aligned} Z &= n\,e\,B \\ B &= \frac{C}{3\pi\eta d_p} \end{aligned}\right\} \qquad (1)$$

where

Z is the electrical mobility, in metres squared per volt second, of a charged aerosol particle;

n is the number of electrical charges;

e is the basic unit of charge (elementary charge), 1,602 177 × 10^{-19} C;

B is the particle mechanical mobility, in seconds per kilogram;

C is the Cunningham correction factor;

η is the gas viscosity, in pascal seconds;

d_p is the equivalent particle electrical mobility diameter, in metres.

The critical particle electrical mobility, Z_{crit}, is directly related to the geometric dimensions of the DEMC. The equivalent particle electrical mobility diameter, d_p, can be determined from equations provided by the instrument manufacturer.

Particles of a certain size or size interval are counted in a condensation nuclei counter (CNC) [also known as a condensation particle counter (CPC)] or electrometer, and the particle number concentration for each size or size interval is determined. By scanning or stepwise changing the voltage of the DEMC, a number size distribution is obtained. The size range from 3 nm to 1 000 nm in electrical mobility diameter can be partly covered by different instruments (see Reference [8]). The DEMC has the advantage that the electrical mobility diameter is approximately equivalent to the projected-area diameter of particles (defined as the diameter of a sphere with the same projected area as the particles being sized) with compact geometries. The entire number concentration is obtained by adding or integrating all size channels.

Though the composition of the sampled particles cannot be obtained, the distribution of surface area and volume concentration in some instances, e.g. if the particles are known to be spherical, can be estimated from calculations provided by the manufacturer or in the literature.

6 Equipment

6.1 General

A DMAS consists of different instrument sections (see Figure 1):

a) pre-separator;

b) particle charger or particle charge conditioner;

c) differential electrical mobility classifier (DEMC), with flow control and high voltage control;

d) particle detector;

e) system controller, with data acquisition and data analysis (typically built-in firmware or dedicated software on a personal computer).

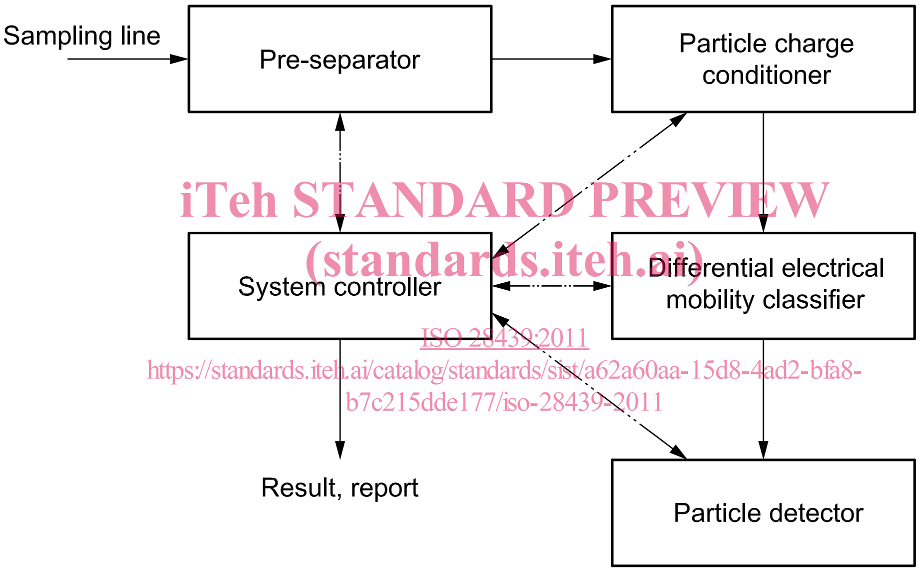

Figure 1 — Major parts of a DMAS

6.2 Sampling line

The aerosol is often sampled with a flexible tube in order to access the breathing zone of a worker. The material of the tube shall be an electrical conductor. Particle diffusion losses should be minimized. This can be accomplished by using tubes of short length. For example, the application of flexible rubber tubes of conducting material of length up to a few metres with an inner diameter of 4 mm or 6 mm ensures a short residence time in the tube (see 11.3.2). The flow in the sampling line shall be laminar.

When sampling highly fluctuating aerosols like welding fumes it is recommended additionally that a buffer vessel be used in order to average the concentration during the scan. The buffer vessel shall be electrically conducting and be earthed. The mean residence time of the buffer vessel shall be related to the scan time. In order to get a relatively stable concentration over the scan time, the volume of the vessel can be chosen in relation to the sample air flow rate according to Condition (2).

$$\frac{V_{\mathrm{v}}}{q_1 \, t_{\mathrm{scan}}} \geqslant 5 \qquad (2)$$

where

V_v is the volume, in metres cubed, of the buffer vessel for the sample air flow rate;

q_1 is the DEMC sample air flow rate, in metres cubed per second;

t_{scan} is the scan time, in seconds.

EXAMPLE For a sample air flow rate of 0,3 l/min ($0,5 \times 10^{-5}$ m^3/s) and a scan time of 2 min (120 s), a vessel of 3 l (3×10^{-3} m^3) is appropriate.

Smaller buffer volumes are preferred if the aerosol agglomerates by coagulation (high concentration of primary particles) (see 11.3.3).

NOTE The state of knowledge at the time of publication allows no recommendation for an upper volume to be made.

6.3 Pre-separator

A pre-separator is required such that large particles above the desired measurement range are precipitated. This can be done, for example, by use of a suitable impactor or cyclone. The pre-separator shall be cleaned and, if necessary, greased regularly.

6.4 Particle charge conditioner

The aerosol is charged with free electrical charges by collisions with gas ions and electrons. The free electrical charges are usually produced by a radioactive source in the air stream, separated by a thin enclosure. Sources like ^{85}Kr, ^{210}Po or ^{241}Am are used. The entire aerosol reaches a charge equilibrium of known distribution (see Reference [9]).

NOTE The charging of non-spherical particles differs from that of spheres. Therefore the distribution of electrical charges as a function of particle size employed in the inversion of the critical electrical mobility into a particle size interval is strictly valid only for spherical particles.

6.5 DEMC

The conditioned aerosol reaches the electrical mobility classification section. A common DEMC comprises an inner and an outer electrode maintained at an electrical potential difference typically between 20 V and 10 000 V (see Figure 2).

The particles are transported in laminar flow along an annular region or tube along with a clean air sheath. The motion of the charged particles depends on their different mobilities, causing them to reach the electrode at different positions. Particles of a narrow electrical mobility range centred on the critical electrical mobility are sampled via a slit towards the end of the annular region and transported into the detection section.

6.6 Aerosol particle detector

The separated aerosol with the specified, critical, electrical mobility is led to a counter which determines the number of particles per unit volume. The most widely used counter is the CPC (CNC). In this device, the aerosol is brought into contact with supersaturated vapour (alcohol or water) which condenses on to the particles. The particles grow rapidly to large droplets, typically several micrometres in diameter, and can then be detected using optical methods. Another detector is the electrometer, which determines the net electrical current provided by the sampled particles.

After passing through the detector, further analysis of the particles is not possible. Additional samplers operated in parallel to the DMAS can be used to collect samples for further analysis, e.g. an electrostatic or thermal precipitator.