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Stationary source emissions — Determination of $PM_{10}/PM_{2,5}$ mass concentration in flue gas — Measurement at low concentrations by use of impactors

Émissions de sources fixes — Détermination de la concentration en masse de $PM_{10}/PM_{2,5}$ dans les effluents gazeux — Mesurage à des faibles concentrations au moyen d'impacteurs

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

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

ISO 23210 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions*.

Introduction

In order to quantify the amount of PM_{10} and $PM_{2,5}$ particles in stationary source emissions or to identify the contribution sources of PM_{10} and $PM_{2,5}$ in ambient air, it is necessary to measure fine particulate matter in the flue gas of industrial sources.

This International Standard describes a measurement method for the determination of mass concentrations of PM_{10} and $PM_{2,5}$ emissions, which realizes the same separation curves as those specified in ISO 7708:1995 for PM_{10} and $PM_{2,5}$ in ambient air. The method is based on the principle of impaction. During sampling, the particle fraction is divided into three groups with aerodynamic diameters greater than 10 µm, between 10 µm and 2,5 µm and smaller than 2,5 µm.

The measurement method allows the simultaneous determination of concentrations of PM_{10} and $PM_{2,5}$ emissions. The method is designed for stack measurements at stationary emission sources.

The contribution of stationary source emissions to PM_{10} and $PM_{2,5}$ concentrations in ambient air can be classified as primary and secondary. Those emissions that exist as particulate matter within the stack gas and that are emitted directly to air can be considered “primary”. Secondary particulate consists of those emissions that form in ambient air due to atmospheric chemical reactions. The measurement technique in this International Standard does not measure the contribution of stack emissions to the formation of secondary particulate matter in ambient air.

This International Standard includes normative references to ISO 12141:2002. The corresponding requirements in ISO 12141:2002 are identical to those in European Standards EN 13284-1:2001 and EN 15259:2007.

Stationary source emissions — Determination of PM_{10}/$PM_{2,5}$ mass concentration in flue gas — Measurement at low concentrations by use of impactors

1 Scope

This International Standard specifies a standard reference method for the determination of PM_{10} and $PM_{2,5}$ mass concentrations at stationary emission sources by use of two-stage impactors. The measurement method is especially suitable for measurements of mass concentrations below 40 mg/m^3 as half-hourly averages in standard conditions (273 K, 1 013 hPa, dry gas). It is an acceptable method for the measurement in the flue gas of different installations, such as cement and steel production plants, as well as combustion processes.

This International Standard is not applicable to the sampling of flue gases that are saturated with water vapour.

This International Standard is not applicable where the majority of the particles are likely to exceed PM_{10}, for example, in the case of raw gases or plant operating failures.

NOTE 1 Measurements of particulate concentrations higher than 40 mg/m^3, as a half-hourly average in standard conditions (273 K, 1 013 hPa, dry gas), can lead to overloading of the collecting plates and backup filters and also could result in shorter sampling times.

NOTE 2 The collecting plates and backup filters can be used for further chemical analysis.

This International Standard cannot be used for the determination of the total mass concentration of dust.

NOTE 3 For data assessment purposes, it can be useful to perform measurements of total particulate matter in parallel to the PM_{10} and $PM_{2,5}$ measurements.

This International Standard describes the design, use and theory of round-nozzle impactors. It does not exclude other types of impactors, provided these systems meet the performance criteria specified in this International Standard in a validation of the impactor performed by an independent testing laboratory.

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 7708:1995, *Air quality — Particle size fraction definitions for health-related sampling*

ISO 12141:2002, *Stationary source emissions — Determination of mass concentration of particulate matter (dust) at low concentrations — Manual gravimetric method*

ISO 20988:2007, *Air quality — Guidelines for estimating measurement uncertainty*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 Flow-related terms

3.1.1
aerodynamic diameter
diameter of a sphere of density 1 g/cm^3 with the same terminal velocity due to gravitational force in calm air as the particle, under prevailing conditions of temperature, pressure and relative humidity

NOTE Adapted from ISO 7708:1995, 2.2.

3.1.2
cut-off diameter
aerodynamic diameter where the separation efficiency of the impactor stage is 50 %

3.1.3
PM_{10}
particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter

NOTE PM_{10} corresponds to the “thoracic convention” as defined in ISO 7708:1995, Clause 6.

3.1.4
$PM_{2,5}$
particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 2,5 µm aerodynamic diameter

NOTE $PM_{2,5}$ corresponds to the “high-risk respirable convention” as defined in ISO 7708:1995, 7.1.

3.1.5
Reynolds number
dimensionless parameter describing a flow

3.1.6
Stokes's number
dimensionless instrument-specific quantity

NOTE See B.2.

3.1.7
Cunningham factor
correction factor taking into account the change in the interaction between particles and the gas phase

NOTE Stokes's law is based on the assumption that the relative gas velocity at the particle edge equals zero. This assumption is not valid for particle sizes close to the mean free path length. Such particles cannot move continuously due to collisions with particles and gas atoms. In this case, Stokes's law has to be amended by a correction factor, i.e. the Cunningham factor. This factor only depends on the mean free path length and the particle diameter.

3.1.8
Sutherland constant
constant characteristic of a gas used for calculating the dependence of the viscosity of a gas on its temperature

3.1.9
aerosol
suspension in a gaseous medium of solid particles, liquid particles or solid and liquid particles having a negligible falling velocity

[ISO 4225:1994, 3.2]

3.2 Instrument-related terms

3.2.1
filter set
separator consisting of two collecting plates and a backup filter

3.2.2
collecting plate
plane filter used for particle collection by impaction

3.2.3
backup filter
plane filter used for collection of the $PM_{2,5}$ particle fraction

3.2.4
collecting plate holder
support of the collecting plate

3.2.5
backup filter holder
punched plate as support of the backup filter

3.2.6
diffuser
conical part in front of the nozzle plates to avoid stall

3.3 Sampling-related terms

3.3.1
measurement site
sampling site

place on the waste gas duct in the area of the measurement plane(s) consisting of structures and technical equipment

NOTE The measurement site consists, for example, of working platforms, measurement ports and energy supply.

3.3.2
measurement section
region of the waste gas duct which includes the measurement plane(s) and the inlet and outlet sections

3.3.3
measurement plane
sampling plane
plane normal to the centreline of the duct at the sampling position

4 Symbols and abbreviated terms

A separation efficiency

BF backup filter

$c_{1,i}$ ith concentration value of the first measuring system

$c_{2,i}$ ith concentration value of the second measuring system

C Cunningham factor

CP2 collecting plate of the second impactor stage

d_{ae} aerodynamic diameter

d_e equivalent volumetric diameter

d_{in} impactor nozzle diameter

d_{nozzle} entry nozzle diameter

d_{50} cut-off diameter

E collection efficiency

f_n mass concentration of water vapour in standard conditions and with dry gas

g acceleration due to gravity

i series element number, $i = 1, 2, 3, \ldots m$

j series element number, $j = 1, 2, 3, \ldots n$

l_{in} impactor nozzle length

m sampled mass

m(BF) particle mass on the backup filter

m(CP2) particle mass on the collecting plate of the second impactor stage

M molar mass

n number of measurement pairs

N number of impactor nozzles

p absolute gas pressure

p_{atm} atmospheric pressure at the measurement site (barometric pressure)

p_n standard pressure

p_{st} difference between the static pressure in the measurement cross-section and the atmospheric pressure at the measurement site

r volume fraction

R gas constant

Re Reynolds number

s distance between the end of the nozzle and the impactor plate

s_D standard deviation of paired measurements

S Sutherland constant

St Stokes's number

T	gas temperature
T_n	standard temperature
T_{crit}	critical temperature
v_{fg}	flue gas velocity
v_{in}	gas velocity in the impactor nozzle
v_{nozzle}	gas velocity in the entry nozzle
v_P	particle drift rate
V	sample volume
V_n	sample volume in standard conditions and for dry gas
$\dot{V}$	volumetric flow rate
WV	water vapour
λ	mean free path length
χ	dynamic shape factor for non-spherical particles
η	dynamic viscosity of the gas
ρ_n	density of the dry gas in standard conditions
$\rho_{n,WV}$	density of water vapour in standard conditions
$\rho_{p,t,h}$	density of the gas in operating conditions
ρ_P	particle mass density
$\rho_{0,P}$	particle unit mass density

5 Principle of the method

5.1 General

In particle measurements, the following three relevant physical characteristics can be distinguished:

— mass concentration (e.g. total dust, PM_{10}, $PM_{2,5}$) and distribution of mass fractions;

— particle number concentration and particle size distribution by number concentration;

— morphology of particles (e.g. shape, colour, optical properties).

The PM_{10} and $PM_{2,5}$ mass concentrations are determined by size-selective separation of gas-borne particles by use of the different inertia of particles. In general, two methods of separation based on the inertia principle can be distinguished:

— impactors (sub-types: e.g. slot-type nozzle impactor, round-nozzle impactor, virtual impactor);

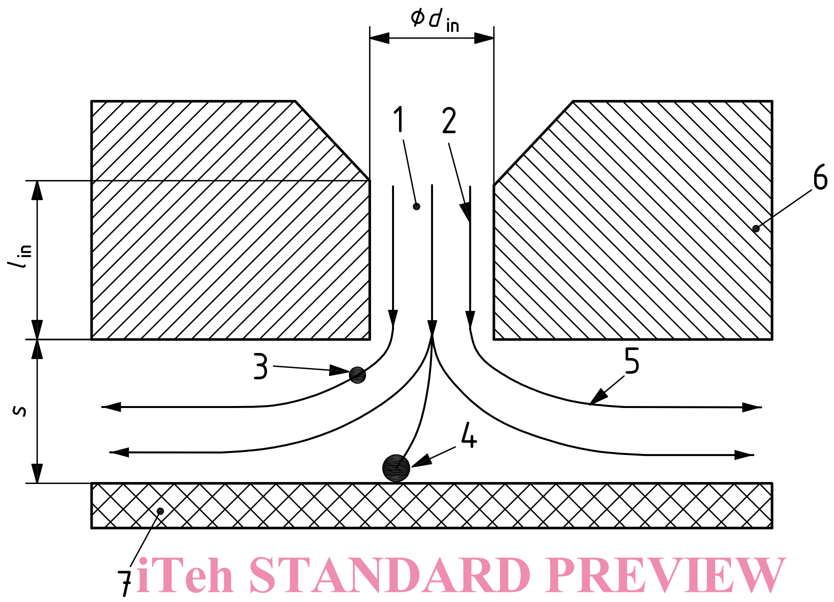
— cyclones (sub-types: e.g. cascade cyclone, sharp-cut cyclone).

Impactors are used at low mass concentrations, whereas cyclones are applied at high mass concentrations.

This International Standard specifies a measurement method for the determination of PM_{10} and $PM_{2,5}$ mass concentrations based on impaction with a round-nozzle impactor.

5.2 Theory of impaction

An impactor separates particles according to their specific aerodynamic diameter. The aerosol is accelerated through a nozzle and then deflected by 90°. Particles with greater aerodynamic diameters are not able to follow the gas flow due to their mass inertia. They are impacted on the collecting plate (see Figure 1).



Key

1 impactor nozzle
2 flow line
3 particle remaining in the flow
4 impacted particle
5 particle trajectory
6 nozzle plate
7 collecting plate

l_{in} impactor nozzle length
s distance between nozzle outlet and collecting plate
d_{in} impactor nozzle diameter

Figure 1 — Principle of impaction

An impactor stage is defined by the so-called cut-off diameter d_{50}. For particles with this aerodynamic diameter, the separation efficiency of the impactor is 50 %. Equation (1) is used to calculate the cut-off diameter d_{50} of a single-stage round-nozzle impactor (see Reference [11] in the Bibliography):

$$d_{50} = \sqrt{\frac{9\pi \, St_{50} \, \eta N d_{in}^3}{4 \rho_{0,P} \, C \dot{V}}} \qquad (1)$$

where

St_{50} is the Stokes's number in relation to the cut-off diameter d_{50};

η is the dynamic viscosity of the gas;

N is the number of impactor nozzles;

d_{in} is the impactor nozzle diameter;

$\rho_{0,P}$ is the particle unit mass density (1 g/cm^3);

C is the Cunningham factor;

$\dot{V}$ is the volumetric flow rate through the impactor in operating conditions.

The following conditions apply to the design and to the application of Equation (1):

a) Distance between nozzle and collecting plate

The ratio of the distance s between the nozzle outlet and the collecting plate to the nozzle diameter d_{in} shall be between

$$0,5 \leqslant s / d_{in} \leqslant 5,0 \quad (2)$$

b) Ratio of nozzle length to nozzle diameter

The ratio of the impactor nozzle length l_{in} to the nozzle diameter d_{in} shall be between

$$0,25 \leqslant l_{in} / d_{in} \leqslant 2,0 \quad (3)$$

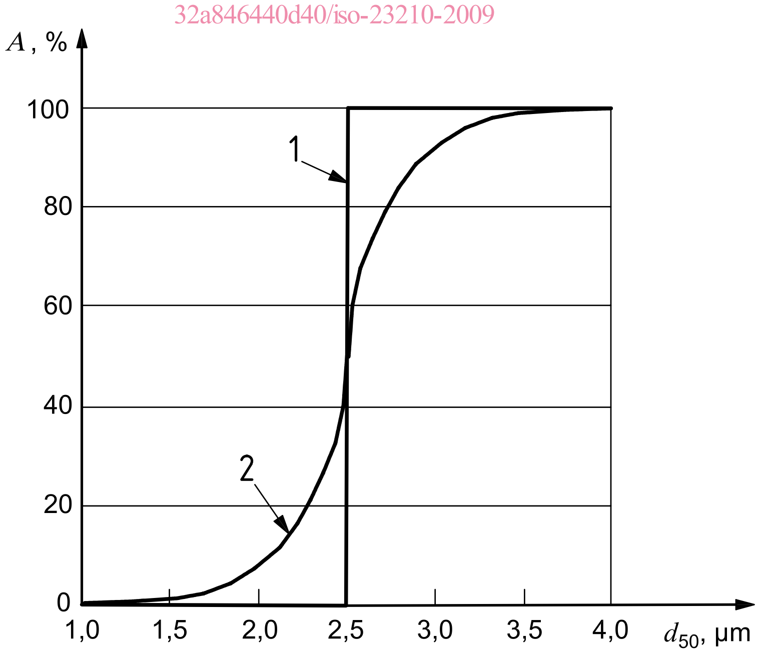
This leads to a uniform flow profile at the nozzle outlet, i.e. the flow has a uniform velocity at the nozzle outlet. If the ratio is too small ($l_{in}/d_{in} < 0,25$), the flow is still non-uniform. If the ratio is too large ($l_{in}/d_{in} > 2,0$), the velocity at the nozzle edge is smaller than the velocity at the centre of the nozzle due to friction.

c) Reynolds number

The Reynolds number Re of the gas flow in the nozzle shall be in the region of laminar flow ($100 < Re < 3\,000$).

5.3 Cut-off diameter

In reality, the particle separation is not ideal. In practice, impactors exhibit separation curves similar to the example shown in Figure 2.



Key

1 ideal

2 real

Figure 2 — Separation efficiency A of an impactor as a function of the cut-off diameter d_{50}

5.4 Cascade impactor

This International Standard specifies a two-stage cascade impactor for the determination of PM_{10} and $PM_{2,5}$ mass concentrations (see Reference [9] in the Bibliography).

NOTE A cascade impactor consists of several impactor stages. The first impactor stage separates the greatest particles on a collecting plate; smaller particles reach the following stages.

The separation curves of PM_{10} and $PM_{2,5}$ emission measurements shall correspond to the separation curves specified for PM_{10} and $PM_{2,5}$ ambient air quality measurements. During sampling, the particles are divided into three fractions, with aerodynamic diameters greater than 10 µm, between 10 µm and 2,5 µm, and smaller than 2,5 µm. Therefore, the measurement method allows the simultaneous determination of emission concentrations of PM_{10} and $PM_{2,5}$.

6 Specification of the two-stage impactor

6.1 General

The two-stage impactor for the determination of PM_{10} and $PM_{2,5}$ concentrations in flue gas described in this International Standard divides the particles into the following three fractions:

a) particles with aerodynamic diameters greater than 10 µm (first impactor stage);

b) particles with aerodynamic diameters between 10 µm and 2,5 µm (second impactor stage);

c) particles with aerodynamic diameters smaller than 2,5 µm (backup filter).

The $PM_{2,5}$ mass corresponds to fraction c), and the PM_{10} mass corresponds to the sum of fractions b) and c). The fraction with aerodynamic diameters greater than 10 µm is not used for the PM_{10} and $PM_{2,5}$ data evaluation.

6.2 Separation curves

The impactor stages for PM_{10} and $PM_{2,5}$ shall be designed such that the separation curves of PM_{10} and $PM_{2,5}$ meet the requirements of the separation efficiencies specified in Tables 1 and 2. The permissible deviations specified in Tables 1 and 2 are absolute percentages concerning the separation efficiencies specified in ISO 7708:1995 (see Figure 3) for the corresponding particle diameters. Furthermore, the requirements of 5.2 shall be fulfilled.

NOTE The shape of the separation curves can differ from the curves shown in Figure 3 due to experimental influences (e.g. detailed design of the impactor and gas flow conditions).

Table 1 — Separation efficiency for the $PM_{2,5}$ impactor stage

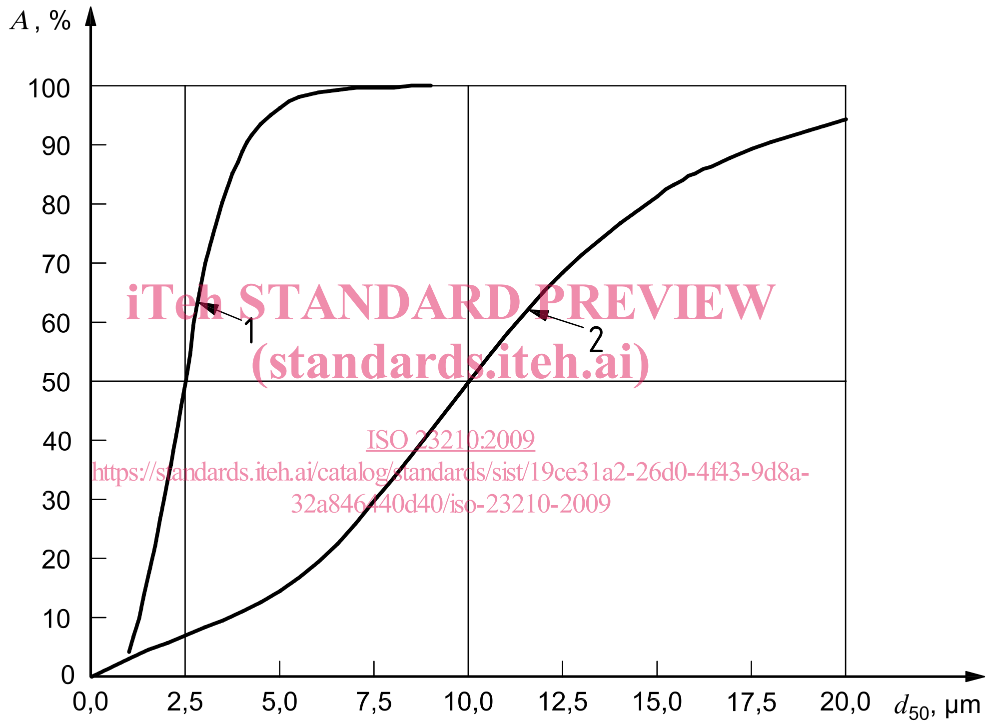
Particle diameter	Separation efficiency for mono-disperse latex aerosol and greased collecting plates	Separation efficiency for mono-disperse latex aerosol and quartz-fibre filters
1,0 µm to 2,5 µm [a]	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±10 %	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±10 %
> 2,5 µm to 10,0 µm [a]	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±15 %	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±30 %

[a] Approximate diameters.

Table 2 — Separation efficiency for the PM_{10} impactor stage

Particle diameter	Separation efficiency for mono-disperse latex aerosol and greased collecting plates	Separation efficiency for mono-disperse latex aerosol and quartz-fibre filters
2,0 µm, to 10,0 µm [a]	Separation efficiency of ISO 7708:1955 at the corresponding particle diameter with a permissible deviation of ±10 %	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±10 %
>10,0 µm to 20,0 µm [a]	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±15 %	Separation efficiency of ISO 7708:1995 at the corresponding particle diameter with a permissible deviation of ±30 %

[a] Approximate diameters.



Key

1 high-risk respirable convention ($PM_{2,5}$)

2 thoracic convention (PM_{10})

A separation efficiency, in percent (%)

d_{50} cut-off diameter, in micrometres (µm)

Figure 3 — Separation curves of PM_{10} and $PM_{2,5}$ specified in ISO 7708:1995

6.3 Verification of the separation curves

The impactor shall be validated in order to prove that the performance criteria specified in 6.2 are met. The validation shall be carried out by a testing laboratory operating an internationally recognized quality-management system.

NOTE Requirements for testing laboratories are specified, for example, in ISO/IEC 17025.

The separation efficiency shall be determined in accordance with the following procedure for each stage and the particle diameter ranges specified in Tables 1 and 2.

The separation efficiency of the impactor stages shall be determined by performing two experiments for each stage with mono-disperse latex aerosols of different particle diameters.