INTERNATIONAL STANDARD

ISO 13271

First edition
2012-06-15

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

Émissions de sources fixes — Détermination de la concentration en masse de $PM_{10}/PM_{2,5}$ dans les effluents gazeux — Mesurage à des hautes concentrations à l'aide des impacteurs virtuels

Reference number
ISO 13271:2012(E)

Contents

Page

Foreword iv
Introduction v
1 Scope 1
2 Normative references 1
3 Terms and definitions 1
4 Symbols and abbreviated terms 4
4.1 Symbols 4
4.2 Abbreviated terms 5
5 Principle 6
5.1 General 6
5.2 Theory of virtual impactor 6
6 Specification of the two-stage virtual impactor 8
6.1 General 8
6.2 Separation curves 8
6.3 Verification of the separation curves 9
6.4 Operating conditions 9
7 Sampling train 12
7.1 Measuring setup 12
7.2 Equipment and working materials 13
8 Preparation, measurement procedure and post-treatment 15
8.1 General 15
8.2 Pre-treatment 15
8.3 Measurement procedure 16
8.4 Weighing procedure 17
8.5 Post-sampling treatment of weighed parts 18
9 Calculation of the results 18
10 Performance characteristics 19
10.1 Virtual impactor load 19
10.2 Detection limit 19
10.3 Measurement uncertainty 19
10.4 Particle losses 19
11 Test report 20
Annex A (informative) Physical property estimation for the calculation of sample volume flow rate 21
Annex B (informative) Errors by deviations from isokinetic sampling 25
Annex C (informative) Example of a two-stage virtual impactor 27
Annex D (informative) Influence of variations in the flue gas temperature and flue gas composition on the Reynolds number 31
Annex E (informative) Entry nozzle 34
Annex F (informative) Equipment list 35
Annex G (normative) Determination of a representative sampling point 37
Annex H (informative) Generation of standard aerosol for virtual impactor calibration 39
Bibliography 40

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 13271 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 determination of mass concentrations of PM_{10} and $PM_{2,5}$ emissions, which realizes the same separation curves as those specified in ISO 7708[1] for PM_{10} and $PM_{2,5}$ in ambient air. The method is based on the principle of gas stream separation using two-stage virtual impactors. This is applicable to higher dust concentrations than the concentrations used for cascade impactors with impaction plates.

The measurement method allows the simultaneous determination of concentrations of PM_{10} and $PM_{2,5}$ emissions. The method is designed for in-stack measurements at stationary emission sources with possible reactive gases and/or high water vapour.

The contribution of stationary source emissions to PM_{10} and $PM_{2,5}$ concentrations in ambient air is 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.

Stationary source emissions — Determination of PM_{10}/$PM_{2,5}$ mass concentration in flue gas — Measurement at higher concentrations by use of virtual 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 virtual impactors. The measurement method is especially suitable for in-stack measurements of particle mass concentrations in flue gas. The method can also be used for flue gas which contains highly reactive compounds (e.g. sulfur, chlorine, nitric acid) at high temperature or in the presence of high humidity.

The International Standard is applicable to higher dust concentrations. Coarse particles are separated into the nozzles with negligible rebound and entrainment phenomena of collected coarse particulates. For the same reason, the artefacts due to high concentrations in gases or emissions are quite limited.

This International Standard is not applicable to the determination of the total mass concentration of dust.

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

3 Terms and definitions

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

3.1
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,[1] 2.2.

3.2
backup filter
plane filter used for collection of the $PM_{2,5}$ particle fraction

[ISO 23210:2009,[7] 3.2.3]

3.3
collection filter
plane filter used for coarse particle collection

3.4
Cunningham factor
correction factor taking into account the change in the interaction between particles and the gas phase

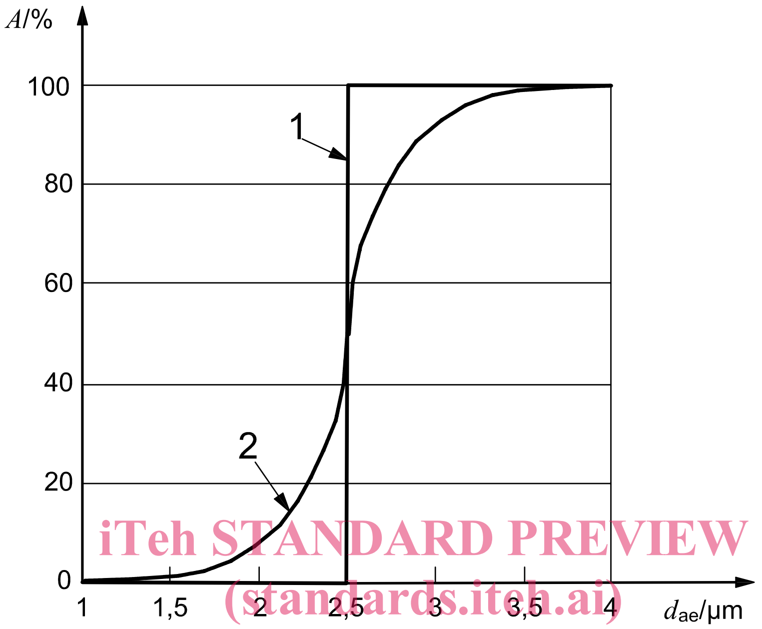
[ISO 23210:2009,[7] 3.1.7]

NOTE See A.2.

3.5
cut-off diameter
aerodynamic diameter where the separation efficiency of the impactor stage is 50 %

[ISO 23210:2009,[7] 3.1.2]

NOTE Particle separation with real impactors is not ideal and exhibits separation curves similar to the example shown in Figure 1.



Key

A	separation efficiency	1	ideal
d_{ae}	aerodynamic diameter	2	real

Figure 1 — Separation efficiency A of an impactor as a function of aerodynamic diameter d_{ae} (adapted from ISO 23210:2009,[7] Figure 2)

3.6
filter holder
substrate holder designed to hold a filter and for which only the filter deposit is analysed (weighed)

[ISO 15767:2009,[4] 2.4]

3.7
measurement plane
sampling plane
plane normal to the centreline of the duct at the sampling position

[ISO 23210:2009,[7] 3.3.3]

3.8
measurement section
region of the waste gas duct which includes the measurement plane(s) and the inlet and outlet sections

[ISO 23210:2009,[7] 3.3.2]

3.9
measurement site
sampling site
place on the flue 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.

[ISO 23210:2009,[7] 3.3.1]

3.10
$PM_{2,5}$
particles which pass through size-selective nozzles with 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,[1] 7.1.

[ISO 23210:2009,[7] 3.1.4]

3.11
PM_{10}
particles which pass through size-selective nozzles with 50 % efficiency cut-off at 10 µm aerodynamic diameter

NOTE PM_{10} corresponds to the "thoracic convention" as defined in ISO 7708:1995,[1] Clause 6.

[ISO 23210:2009,[7] 3.1.3]

3.12
Reynolds number
Re

$$Re = \frac{\rho v l}{\eta}$$

where

ρ is the mass density;

v is the gas velocity in the particle acceleration nozzle;

l is the length;

η is the dynamic viscosity.

NOTE 1 Adapted from ISO 80000-11:2008,[8] 11-4.1.

NOTE 2 "Dimensionless" parameter (parameter of dimension 1) describing flow conditions.

3.13
Stokes's number
St

$$St = \frac{\rho_{0,\mathrm{P}} d_{\mathrm{ae}}^2 C_{\mathrm{m}} v}{9 \eta D_0}$$

where

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

d_{ae} is the aerodynamic diameter (m);

C_m is the Cunningham factor;

v is the gas velocity in the particle acceleration nozzle (m/s);

η is the dynamic viscosity of the gas (Pa s);

D_0 is the particle acceleration nozzle diameter (m).

NOTE 1 Adapted from ISO 23210:2009,[7] B.2.

NOTE 2 An instrument-specific “dimensionless” parameter (parameter of dimension 1) describing a measure of the inertial movement of a particle in gas stream near an obstacle.

3.14
particle acceleration nozzle
acceleration nozzle used for accelerating particle-laden gas before separation takes place in the particle collection nozzle

3.15
particle collection nozzle
collection nozzle used for coarse-particle separation

4 Symbols and abbreviated terms

4.1 Symbols

A	separation efficiency
C_m	Cunningham factor
D_0	particle acceleration nozzle diameter
D_1	particle collection nozzle diameter
d_{ae}	aerodynamic diameter
d_{entry}	internal diameter of the entry nozzle
d_{50}	cut-off diameter
i	series element number, $i = 1,2,3,\ldots m$, or a subscript to identify the particle fraction ($i =$ 2,5 µm, 10 µm)
j	series element number, $j = 1,2,3,\ldots n$
l_0	impactor nozzle length
m_{BF}	particle mass on the backup filter
m_{CF2}	particle mass on the collection filter of the second separation stage
N	number of impactor nozzles
n	number of measurement pairs
p_{amb}	ambient pressure at the measurement site
p_n	standard pressure

p_{st}	difference between the static pressure in the measurement cross-section and the atmospheric pressure at the measurement site
q_V	volume flow rate at operating conditions
q_{Vn}	volume flow rate under standard conditions and for dry gas
q_{V0}	volume flow rates per nozzle at operating conditions for total flow
q_{V1}	volume flow rates per nozzle at operating conditions for minor flow
q_{V2}	volume flow rates per nozzle at operating conditions for major flow
Re	Reynolds number
St_{50}	Stokes's number in relation to the cut-off diameter d_{50}
s	distance between the end of the particle acceleration nozzle and the top of the particle collection nozzle
T	gas temperature
T_n	standard temperature
$u(\gamma)$	standard uncertainty of paired measurements
v	gas velocity at particle acceleration nozzle
v_{fg}	flue gas velocity
V_n	sample volume under standard conditions and for dry gas
$\gamma_{n,H_2O,v}$	mass concentration of water vapour under standard conditions and with dry gas
$\gamma(PM_{2,5})$	concentration of $PM_{2,5}$
$\gamma(PM_{10})$	concentration of PM_{10}
$\gamma_{1,i}$	ith concentration value of the first measuring system
$\gamma_{2,i}$	ith concentration value of the second measuring system
η	dynamic viscosity of the gas
$\rho_{n,H_2O,v}$	density of water vapour under standard conditions
$\rho_{0,P}$	particle density (1 g/cm^3)
ξ	minor flow ratio at impactor stage

4.2 Abbreviated terms

BF	backup filter
CF1	collection filter of the first separation stage
CF2	collection filter of the second separation stage

5 Principle

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;

— 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.

This International Standard specifies a measurement method for the determination of PM_{10} and $PM_{2,5}$ for higher mass concentrations using two-stage virtual impactors based on the principle of gas stream separation without impaction plates, and with negligible rebound and entrainment phenomena of collected coarse particulates.

5.2 Theory of virtual impactor

Size separation by a virtual impactor stage is based on the inertia of accelerated and decelerated particles in a gas flow. The principle of operation of a separation stage and the major parameters governing the performance are shown in Figure 2.

The separation stage consists in its basic configuration of coaxially oriented particle acceleration and collection nozzles whose diameters are designated D_0 and D_1, respectively (see Figure 2). The particle-laden gas enters the nozzles and accelerates depending on D_0 and the total flow rate, and part of the stream is directed to the particle collection nozzles. Flow rate through particle collection nozzles, which is called minor flow rate, is approximately 10 % of the total flow rate. The major fraction or major flow is redirected and bypasses the particle collection nozzles. Consequently, particles above a certain aerodynamic size (cut-off size) are entrained in the minor flow received by the particle collection nozzles and are collected on a filter. Fine particles smaller than this cut-off size stay in the major stream and are directed into the next separation stage.

The performance of a separation stage is characterized by a separation efficiency curve. Due to the specific characteristics of this separation process, there is always a residue of particles larger than the minor flow cut-off size and particles smaller than major flow cut-off.

A separation stage is specified with the cut-off diameter, d_{50}. For particles with this aerodynamic diameter, the separation efficiency of the impactor stage is 50 %. Formula (1) is used to calculate the cut-off diameter, d_{50}:

$$d_{50} = \sqrt{\frac{9\pi St_{50}\eta D_0^3}{4\rho_{0,\mathrm{P}} C_\mathrm{m} q_{V0}}} \qquad (1)$$

where

St_{50} is the Stokes's number in relation to the cut-off diameter, d_{50}, an instrument-specific quantity;

η is the dynamic viscosity of the gas;

q_{V0} is the total volume flow rate per nozzle under operating conditions;

D_0 is the particle acceleration nozzle diameter;

$\rho_{0,\mathrm{P}}$ is the particle density (1 g/cm^3) (the inertial cut-off diameter is given in terms of an aerodynamic diameter);

C_m is the Cunningham factor.

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

a) for the design of the separation stages, the value of the St_{50} shall be chosen (Reference [10]) to be

$0{,}4 \le St_{50} \le 0{,}5$

b) the ratio of distance between the end of the particle acceleration nozzle and the top of the particle collection nozzle, s, to the particle acceleration nozzle diameter, D_0, shall be

$0{,}8 < s/D_0 < 2$

c) the ratio of particle acceleration nozzle length, l_0, to particle acceleration nozzle diameter, D_0, shall be

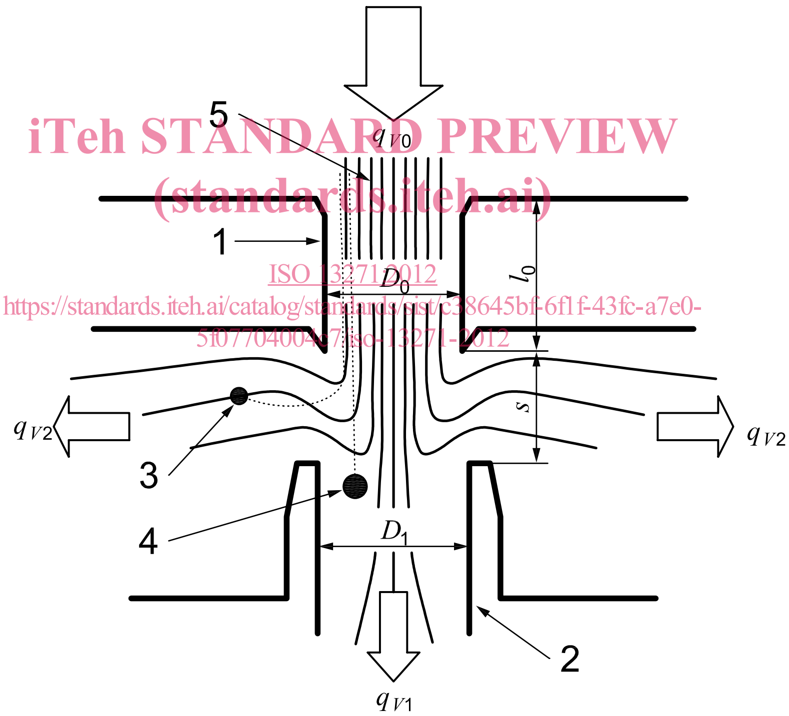
$l_0/D_0 < 2{,}5$

d) the ratio of particle collection nozzle diameter, D_1, to particle acceleration nozzle diameter, D_0, shall be

$D_1/D_0 \approx 1{,}33$

e) Reynolds number, Re, of the gas flow in the particle acceleration nozzle shall be in the region of laminar flow

$100 < Re < 3\ 000$



Key

1 particle acceleration nozzle
2 particle collection nozzle
3 trajectory of fine particles to be measured
4 trajectory of coarse particles
5 stream lines

D_0 particle acceleration nozzle diameter
D_1 particle collection nozzle diameter
l_0 impactor nozzle length
s distance between the end of the particle acceleration nozzle and the top of the particle collection nozzle
q_{V0} total flow rate
q_{V1} minor flow rate
q_{V2} major flow rate

Figure 2 — Principle of the virtual impactor

