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Stationary source emissions — Determination of concentration and mass flow rate of particulate material in gas-carrying ducts — Manual gravimetric method

Émissions de sources fixes — Détermination de la concentration et du débit-masse de matières particulaires dans des veines gazeuses — Méthode gravimétrique manuelle

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Contents

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Annexes

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.

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.

International Standard ISO 9096 was prepared by Technical Committee ISO/TC 146, *Air quality*, Sub-Committee SC 1, *Stationary source emissions*.

Annexes A, B, C, D, E and F form an integral part of this International Standard. Annex G is for information only.

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Stationary source emissions — Determination of concentration and mass flow rate of particulate material in gas-carrying ducts — Manual gravimetric method

WARNING — SAFETY PRECAUTIONS

GENERAL

Sampling operations may involve a variety of hazards depending on the circumstances. All those concerned, e.g. management, sampling operators and control authorities, shall consider the likely hazards adequately beforehand.

If hazards cannot be eliminated, it will be necessary to make appropriate safety arrangements with regard to any specific local, national or international regulations before sampling operations commence.

The hazards most likely to be encountered and the means of reducing them include those described below.

On every occasion, plant management and plant operators should be aware that sampling operations are taking place. Management should consider what appropriate safety procedures, e.g. work permits, should be adopted and ensure that they are understood by all those likely to be concerned.

HAZARDS TO SAMPLING OPERATORS

a) Working at heights or under conditions of difficult access — Consider a means of escape and the need for guard rails and base boards (see 9.5), warning systems, etc. Telecommunication will be desirable at remote locations. It is recommended that operators do not work alone.

b) Exposure to toxic, corrosive or hot gases or dusts from the access ports or from elsewhere in the processing plant — Consider circumstances, monitoring or warning systems, personal protective equipment, etc.

c) Electrical hazards, from electrical equipment or electrostatic charge — Consider equipment protection, earthing, etc. (see 9.5).

d) Noise and heat from the plant or equipment — Consider protective measures.

e) Handling of heavy or bulky equipment — Consider lifting arrangements and accessibility of sampling location.

HAZARDS TO OTHER PERSONNEL

a) Objects falling from the platform — Consider warning signs, barricading, etc.

b) Presence of temporary equipment, e.g. cables causing trip hazards — Consider warning signs etc.

HAZARDS TO PLANT

a) Ignition of flammable gases — Consider using non-sparking equipment, etc.

b) Equipment dropped into duct system — Take special care that sampling heads etc. cannot become detached.

1 Scope

This International Standard specifies a manual gravimetric method for the measurement of the concentration and mass flow rate of particulate matter in a moving gas stream in confined spaces such as ducts, chimneys and flues. This method can be used to determine concentrations ranging from 0,005 g/m^3 to 10 g/m^3. For concentrations under 0,050 g/m^3, the inaccuracy of this method will be greater than $\pm$ 10 % (see clauses 12 and 14).

It is primarily a reference method for the determination of particulate matter emitted from stationary sources and it can also be used for calibrating automatic continuous particulate monitors. The method should be applied as much as possible under steady state conditions of the gas flow in the

duct. It is not suitable for use on ventilation or air conditioning systems, indoor atmospheres, or gases carrying droplets.

This International Standard also sets out requirements for the design features of apparatus which can be used for the determinations if correctly used and indicates basic requirements for the positioning of sampling facilities.

If any of the requirements of this International Standard are not fulfilled, the method can still be applied in special cases but the uncertainty on particulate concentration or flow rate may be larger (see clause 14).

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 3966:1977, *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 access port: A hole in the duct at the extremity of a sampling line, through which the sampling probe is inserted [see figure 1 and *sampling line* (3.15)].

3.2 actual conditions: Temperature and pressure at the sampling points.

3.3 cumulative sampling: The collection of a single composite sample obtained by sampling for the required period at each sampling point in turn.

3.4 duct; flue; chimney; stack: An enclosed structure through which gases travel.

3.5 effective pressure: The difference between the pressure at the sampling point and the pressure of the ambient air at equal altitude.

3.6 gas: A mixture of gaseous compounds or elements which may carry particulate matter flowing in a duct.

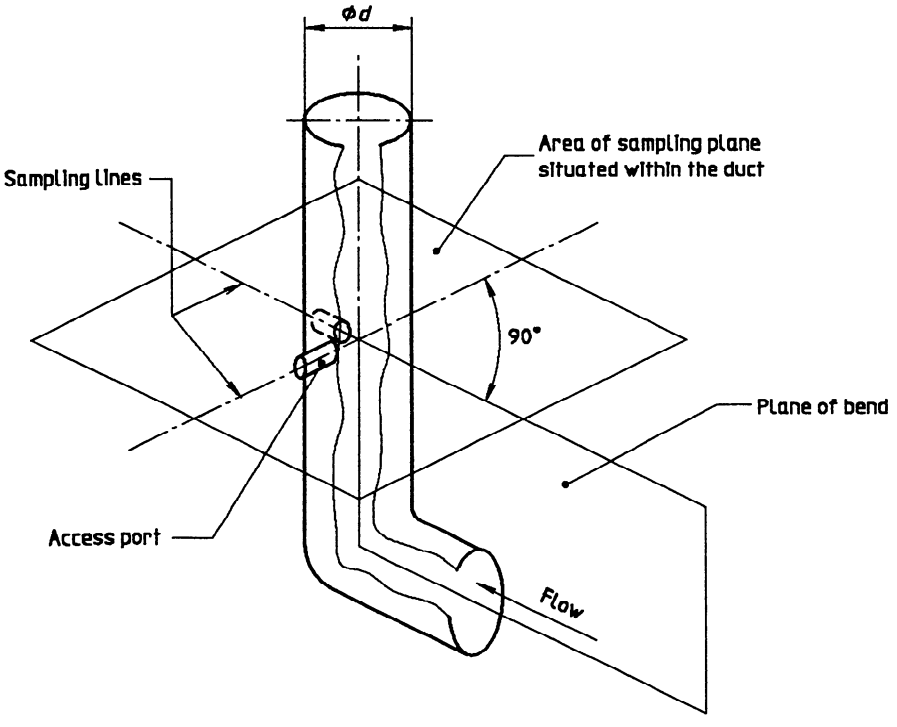


Figure 1 — Illustration of definitions in relation to a circular duct

3.7 hydraulic diameter: The characteristic dimension of a duct cross-section defined by

$$\frac{4 \times \text{Area of sampling plane}}{\text{Perimeter of sampling plane}}$$

3.8 incremental sampling: The collection and removal of individual samples from each sampling point.

3.9 isokinetic sampling: Sampling at a rate such that the velocity and direction of the gas entering the sampling nozzle (v'_N) is the same as that of the gas in the duct at the sampling point v'_a (see figure 2).

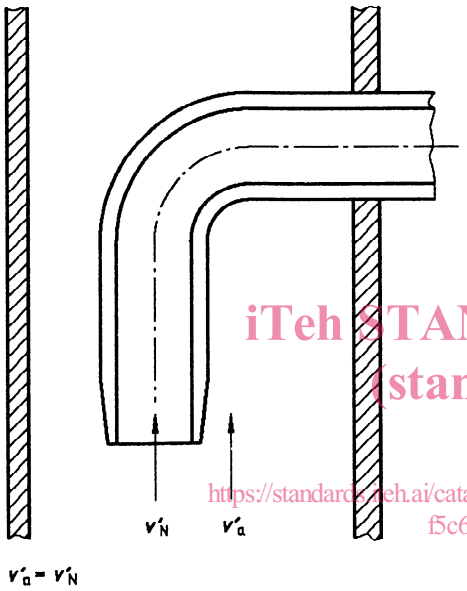


Figure 2 — Isokinetic sampling

3.10 particulate concentration: Mass of particulate matter per unit volume of duct gas at defined gas temperature and pressure.

3.11 particulate flow rate: Mass of particulate matter contained in a duct gas flow per unit time.

3.12 particles; particulate matter: Solid particles, of any shape, structure or density, dispersed in the continuous gas phase.

3.13 representative gas sample: A gas sample having the same mean particulate concentration as prevails in the sampling plane during sampling.

3.14 sampling plane: The plane normal to the centreline of the duct at the sampling position (see figure 1).

3.15 sampling line: The line in the sampling plane along which the sampling points are located (see figure 1), bounded by the inner duct wall.

3.16 sampling point: Specific location on a sampling line at which a sample is extracted.

3.17 sampling location: A suitable position for carrying out sampling in the duct.

3.18 site: Works or plant where sampling is to be carried out.

3.19 standard conditions: Standard temperature and pressure of the gas, i.e. 273 K and 101,3 kPa.

4 Symbols with their corresponding units, subscripts and index

4.1 Symbols and their corresponding units

See table 1.

4.2 Subscript and index

See table 2.

Table 1 — Symbols and their corresponding units

Symbol	Meaning	Unit
a	Effective nozzle area	m^2
A	Sampling plane area	m^2
c	Particulate concentration	g/m^3
δ	Thickness of nozzle wall at the tip	m
d	Duct diameter at sampling plane	m
d_H	Hydraulic duct diameter at sampling plane	m
d_{N1}	Inner nozzle diameter	m
d_{N2}	Outer nozzle diameter	m
d_o	Orifice diameter	m
f	Water vapour concentration	kg/m^3
i	Individual position on sampling line (diameter or radius)	—
K	Calibration factor	—
l	Characteristic length	m
l_1	Greater side length of sampling plane	m
l_2	Smaller side length of sampling plane	m
m	Collected particulate mass	g
M	Molar mass	kg/kmol
n_d	Number of sampling points on sampling diameter	—
n_{dia}	Number of sampling diameters (sampling lines)	—
n_r	Number of sampling points on sampling radius (0,5d)	—
n_1	Number of divisions of l_1	—
n_2	Number of divisions of l_2	—
p	Absolute pressure	Pa
p_{am}	Ambient pressure	Pa
p_e	Effective pressure ($p_e = p - p_{am}$)	Pa
Δp	Differential pressure across flow measuring device	Pa
q_m	Particulate flow rate in duct	g/h
q_V	Gas volumetric flow rate	m^3/h
r	Volume fraction of gaseous component	—
ρ	Gas density	kg/m^3
t	Sampling time (total)	h
Δt	Sampling time per sampling point	h
T	Temperature (absolute)	K
Θ	Temperature	°C
v	Gas velocity	m/s
V	Gas volume	m^3
V_m	Molar volume of a gas	$m^3/kmol$
x_i	Distance from wall to individual sampling point along diameter or radius	m

Table 2 — Subscript and index

Subscript or index	Meaning
a	Actual conditions in sampling plane
g	Any gas measuring device
i	Individual value
n	Standard conditions
N	Nozzle
o	Orifice
Pt	Pitot tube
w	Water vapour
′	Moisture included

5 Principle

A sharp-edged nozzle is positioned in the duct facing into the moving gas stream and a sample flow of the gas is extracted isokinetically for a measured period of time. To allow for non-uniformity of the distribution of particulate concentration in the duct, samples are taken at a pre-selected number of stated positions in the duct cross-section. The particulate matter entrained in the gas sample is separated by a filter medium, then dried and weighed. The particulate concentration is calculated from the weighed particulate mass and the gas sample volume. The particulate mass flow rate is calculated from the particulate concentration and the duct gas volumetric flow rate. The particulate mass flow rate can also be calculated from the weighed particulate mass, the sampling time and the areas of the sampling plane and the nozzle opening.

6 Summary of the method

A representative gas sample is withdrawn from the source. The degree to which this sample represents the total gas flow depends on

— homogeneity of the gas velocity within the sampling plane;

— a sufficient number of sampling points in the sampling plane;

— isokinetic withdrawal of the sample.

Normally the gas has to be sampled at more than one sampling point in the sampling plane, dependent on the sampling plane area. This plane is usually divided into equal areas, at the centres of which gas is withdrawn (see annex B). To determine the particulate concentration in the plane, the nozzle is moved from one sampling point to the other, extracting gas isokinetically at each point. Sampling periods should be equal for each sampling point, resulting in a composite sample. If equal sampling areas cannot be chosen, the sampling period shall be proportional to the sampling area.

The sample is extracted through a sampling train, which principally consists of

— a sampling probe tube with entry nozzle;

— a particle separator, in-stack or external;

— a gas metering system, in-stack or external; and

— a suction system.

The particle separator and/or the gas metering system may be either located in the duct, or placed outside the duct.

Illustrations of sampling trains are given schematically in figures 3 and 4. The numbers in these figures correspond to the items listed in table 3 and are different from those used in figures 5 and 6 and in clauses 7 and 13.

It is necessary to avoid condensation of vapour (water, sulphuric acid, etc.) in the sampling train during gas sampling, because it will interfere with particle separation, particulate condition and flow measurement. To this end, the probe tube, the particle separator and the gas flow measuring device are heated above the relevant dew-point.

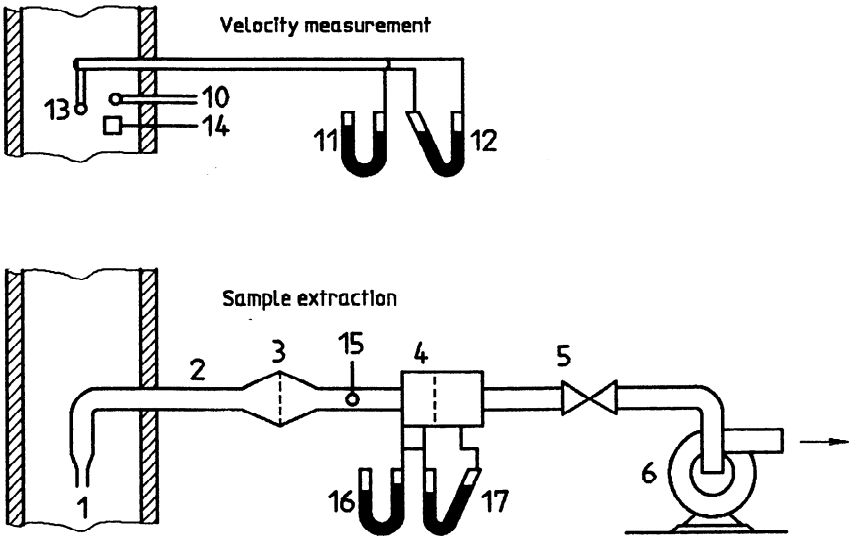
The water vapour may intentionally be removed downstream of the particle separator, to make use of a dry gasmeter for the measurement of sample gas volume, if the water vapour content of the duct gas does not vary appreciably during sampling.

For isokinetic sampling, the gas velocity at the sampling point in the duct has to be measured, and the corresponding sample gas flow has to be calculated and adjusted.

Normally, a Pitot static tube is used for the measurement of duct gas velocity. If the sample gas flow measuring device is used within the duct, the relation between the measured pressure drop and the Pitot static tube differential pressure is simple, facilitating the adjustment to isokinetic conditions. If the gas metering device is located outside the duct, the calculation of the isokinetic sample gas flow rate is more complicated. The calculation may also include the duct gas density under standard conditions (which may be derived from the dry gas composition and the moisture content), the temperature and static pressure of the gas in the duct and the gas metering device, and the water vapour content of the duct gas, if the sample gas flow is measured after water removal.

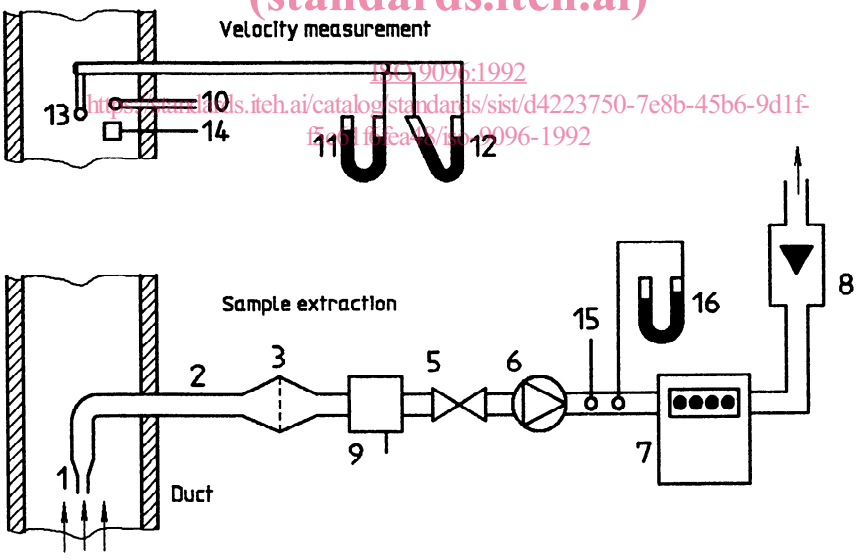
After sampling, the collected particulate matter is completely recovered (which can necessitate cleaning of the probe and nozzle), dried and weighed.

Methods of calculating the particulate concentration and mass flow in the duct are presented in clauses 7 and 13. An alternative method of calculation of the particulate mass flow rate in the duct is presented in annex F.



The numbers correspond to items listed in table 1.

Figure 3 — Example of a measuring equipment arrangement (see 8.2), without water removal upstream of the gas metering device



The numbers correspond to items listed in table 1.

Figure 4 — Example of a measuring equipment arrangement (see 8.2), with water removal upstream of the gas metering device

7 Review of measurements and calculations

A coherent picture of the necessary measurements and calculations for the determination of the particulate concentration and mass flow is given in the schematic diagrams of figures 5 and 6. These diagrams are related to the examples of sampling trains presented in figures 3 and 4 respectively. Other sampling train arrangements (filtration and/or sample flow measurement in-stack) and calculations (annex F) are possible, provided their performance is accurate enough to meet the needs of this International Standard.

From figure 5 (water removal prior to gas metering) it can be seen that, for the calculation of the duct gas velocity (8), measurement of temperature (3), static pressure (4), water content (6) and composition (5) of the duct gas will enable calculation of the duct gas density (7). This is included in the formula for the velocity calculation together with the measured differential pressure (1) if a Pitot tube is used. Using the duct gas velocity (8) and the area of the duct section (2), the gas flow rate through the duct at different gas conditions (9, 10, 11) can be calculated.

For isokinetic sampling, a convenient nozzle diameter is chosen, depending on pump capacity, duct gas velocity, particulate concentration and sampling time. The flow rate for isokinetic sampling (12) is determined by the nozzle diameter (13), the duct gas velocity at the sampling point (8), the gas conditions in the duct (3, 4) and the gas meter (16, 17), and the water content. The sample flow (14) is adjusted accordingly.

The sample gas volume (15) is measured and the reading is converted to standard conditions (21), for which the static pressure (16) and the temperature (17) at the gas meter are used.

The filter material for the collection of particulate matter is conditioned and weighed (18) and is then conditioned and weighed again after collection of particulate matter, including that which was deposited in the sampling train before the filter (19). This will give the total mass of collected particulate matter.

The particulate concentration (22) is calculated as the ratio of the quantity of particulate matter collected (18, 19) to the gas sample volume reduced to standard gas conditions (21).

Finally, the particulate mass flow rate (23) can be obtained by multiplying the particulate concentration (22) by the gas flow rate through the duct (11).

If incremental sampling is used in a given sampling plane, particulate concentrations are averaged, by giving each particulate concentration a weighting factor according to the corresponding gas flow rate through the duct.

From figure 6 (no water removal prior to gas metering), it can be seen that the calculation of the flow rate of moist gas through the duct under standard conditions (10) follows the same path as in figure 5. However, the isokinetic sampling flow rate (12) is calculated by relating the differential pressure of the Pitot tube (1) to the pressure drop in the flow rate measuring device in the sampling equipment (14), allowing for the different pressures (4, 16) and temperatures (3, 17) and the suction nozzle diameter (13).

In this example, a conversion to dry gas conditions is not applied. The moist sample gas volume, reduced to standard conditions (20), is derived from the moist sample flow rate (14) and the sampling time (24). Knowing the moisture content of the gas, however, the particulate concentration can also be calculated on a dry gas basis.

The particulate concentration based on moist gas, reduced to standard conditions (22), is calculated from this sample gas volume (20) and the filter weights (18, 19). The particulate flow rate (23) is found by multiplying this particulate concentration (22) by the moist gas flow rate in the duct at standard conditions (10).