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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.

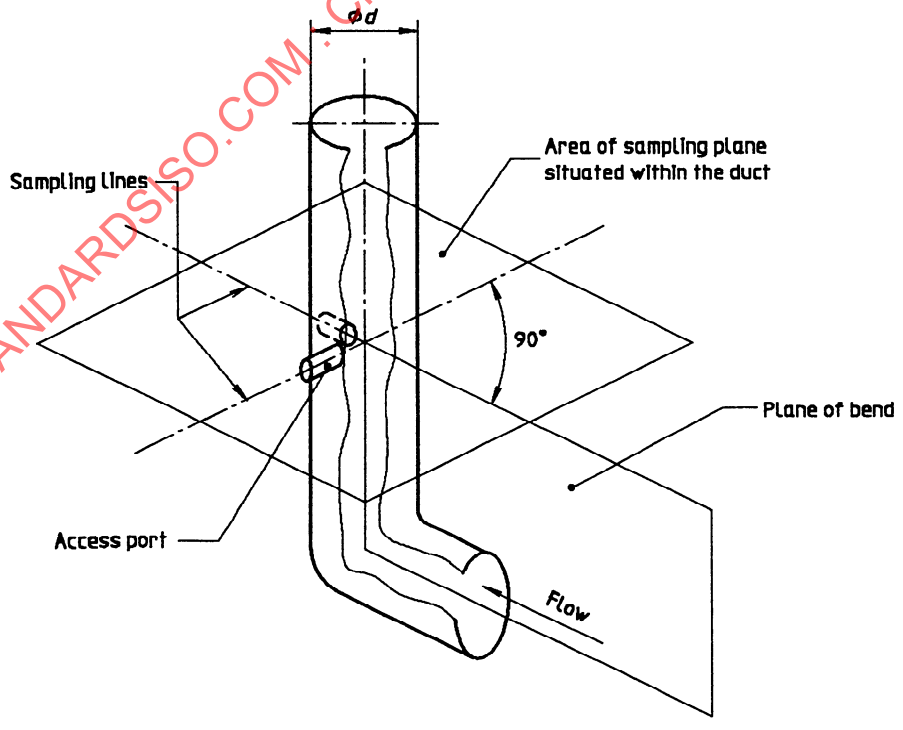


Figure 1 — Illustration of definitions in relation to a circular duct

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).

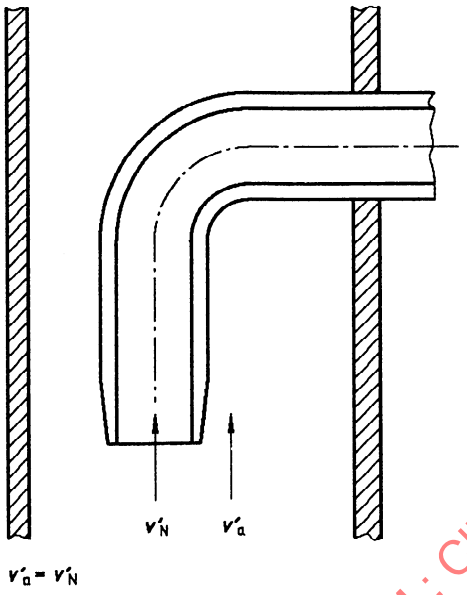


Figure 2 — Isokinetic sampling

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.

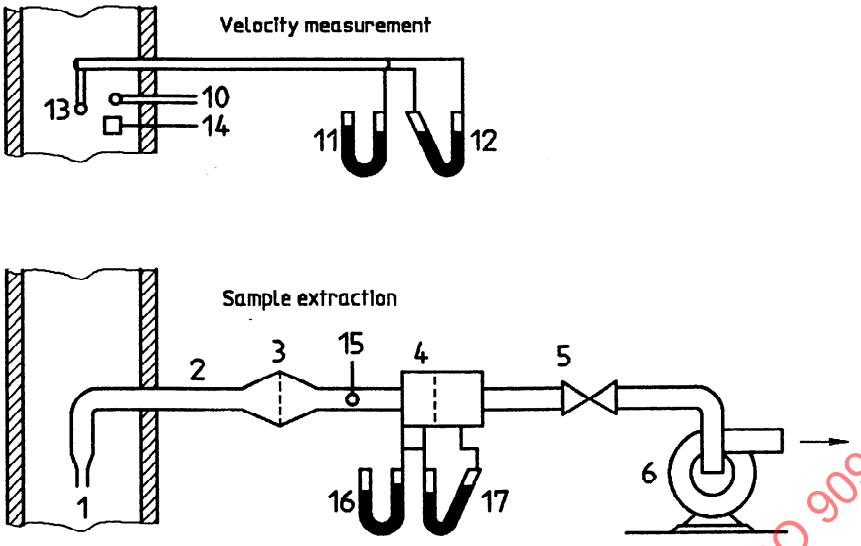
The water vapour may intentionally be removed downstream of the particle separator, to make use of a dry gasmeter for the measurement of sample gas volume, if the water vapour content of the duct gas does not vary appreciably during sampling.

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.

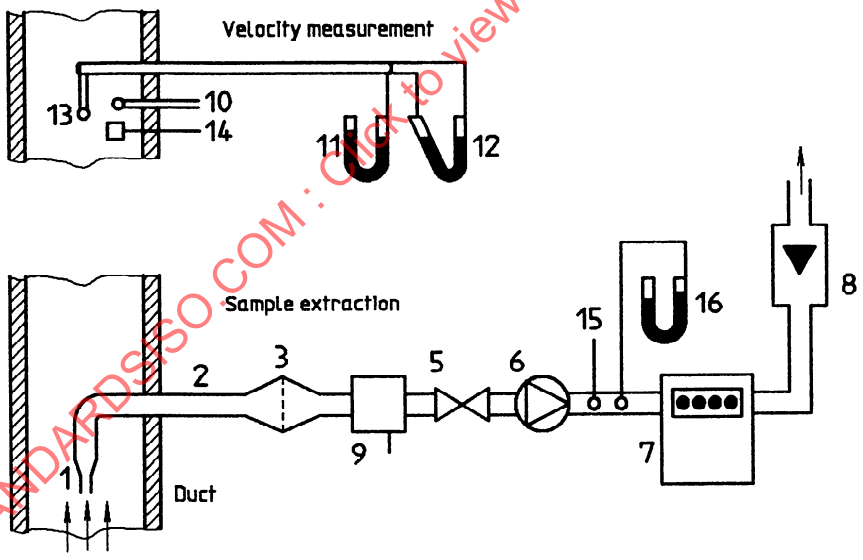
After sampling, the collected particulate matter is completely recovered (which can necessitate cleaning of the probe and nozzle), dried and weighed.

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).

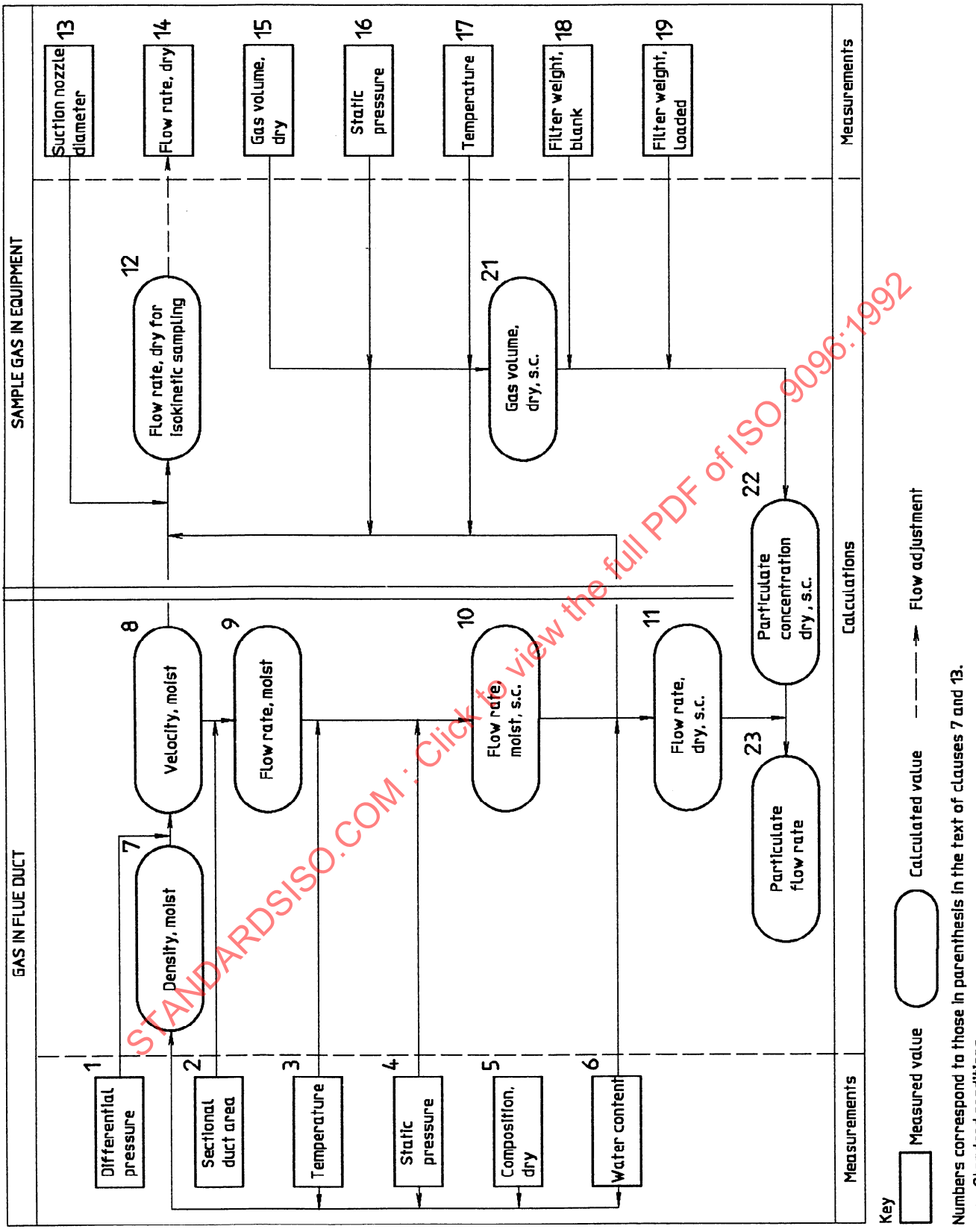


Figure 5 — Diagram of measurement and calculation, with water removal before measurement of gas sample volume

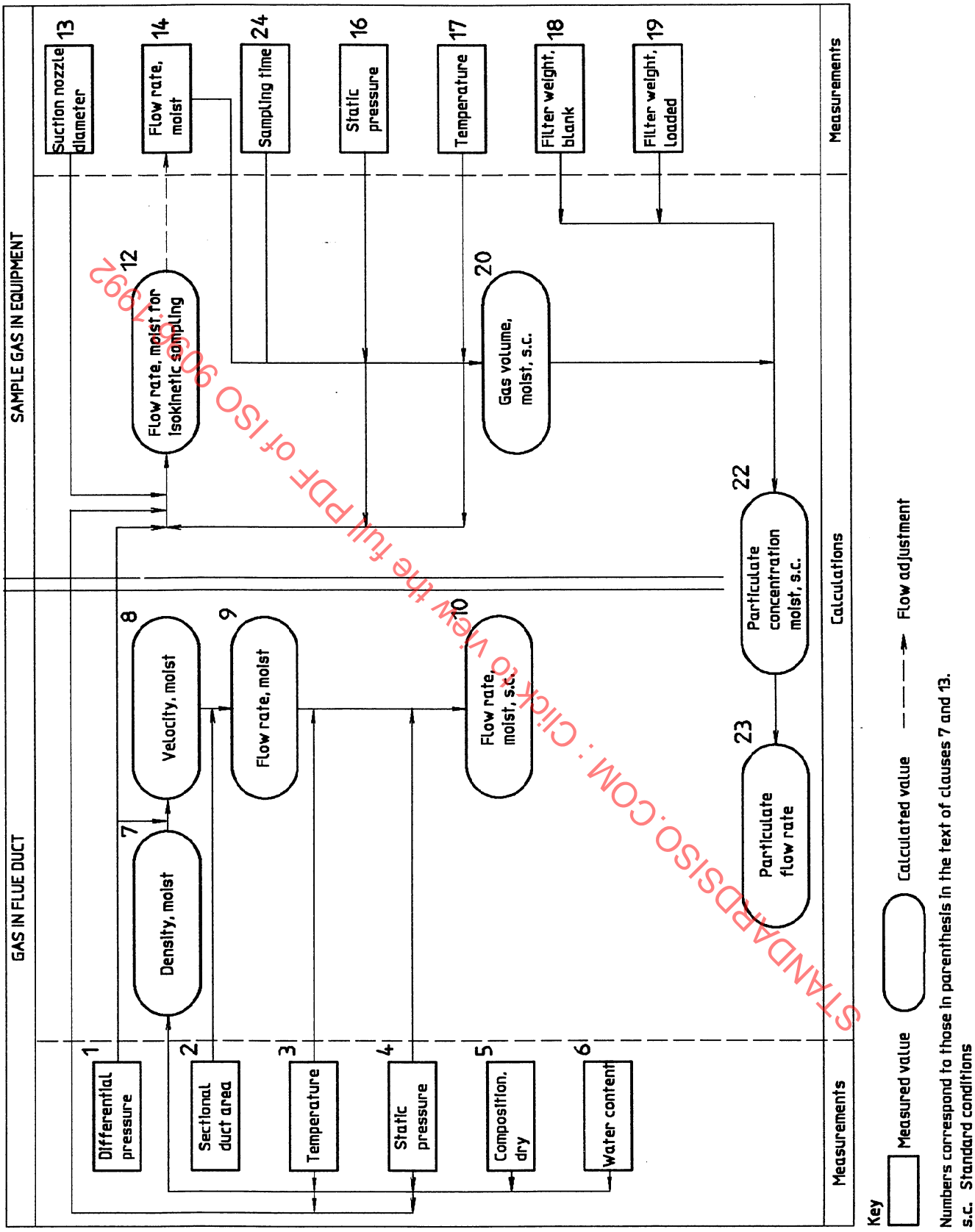


Figure 6 — Diagram of measurement and calculation, without water removal before measurement of gas sample volume

8 Apparatus

8.1 General

Different types of sampling apparatus may have particular features that render them suitable only for selected applications (e.g. only for the normal range of boiler flue gas temperatures, or for low concentrations of particulate matter, or for a certain size of duct). Use, wherever possible, the arrangements of measuring equipment given in figures 3 and 4. The numbers in these figures correspond to the items listed in 8.2 and are different from those used in figures 5 and 6 and in clauses 7 and 13.

Sampling and flow measuring apparatus to be used in accordance with this International Standard shall, wherever possible, include facilities for securing the apparatus in the access port and for minimizing the ingress of air or the escape of gases through the access port. The size of the access port shall be such that the entry nozzle will not be damaged during insertion.

Items of apparatus and their requirements complying with this International Standard are listed in table 3.

A general requirement is that the materials used in the apparatus shall be resistant to corrosive gases and prevailing temperatures. Rough internal surfaces, which might cause deposition of particles, should be avoided. The recovery of particles from these surfaces may be difficult. Also, degradation of the filter by corrosive gases and/or high temperatures may result.

8.2 List of equipment for measurement of particulate concentration

Two gas measuring methods can be distinguished:

— a gas flow measurement (Method I);

— a gas volume measurement (Method II).

If an orifice plate is applied (Method I), the water vapour content of the sample gas is generally maintained (see figure 3). This device can also be used to adjust and maintain isokinetic sampling. If an integrating dry gas meter is applied (Method II), the water vapour shall be removed before the gas enters the meter (figure 4). The gas meter will enable an accurate measurement of the sample gas volume, whereas a separate gas flow measuring device (e.g. a variable area flowmeter) is essential to adjust and maintain isokinetic sampling.

Table 3 summarizes the equipment parts necessary for the measurement of particulate concentration and mass flow.

Part numbers 1 through 17 correspond to the numbers in figures 3 and 4.

Table 3 — List of equipment parts

Part number	Part	Design	Specification
1	Entry nozzle		See 8.3
2	Probe tube		See 8.4
3	Particle separator		See 8.5. With an efficiency of ⩾ 98,0 % for particles of 0,3 mm
4	Sampling flow rate measuring device (Method I)	Orifice plate, flow-meter, equivalent	Volumetric flow rate and/or total gas volume, accurate to within ± 2 %
5	Sampling flow rate control device	Two controls advisable (one for fine adjustment), a stop valve for blocking the gas flow	
6	Exhauster	Pump (Method II), ventilator, fan ejector	Capable of extracting gas sample at required rate against resistance imposed by nozzle, tube, filter, orifice, etc. When employing a gas-meter, the pump shall be gas-tight
7	Gas volume meter (Method II)	Integrating dry gas meter	Gas volume accurate to within ± 2 % When employing a gas-meter, the pump shall be gas-tight

Part number	Part	Design	Specification
8	Sampling flow rate measuring device (Method II)	Orifice plate, rotameter, equivalent	To control isokinetic sampling, accurate to within ± 5 %
9	Water removing device (Method II)	Condenser, dryer (e.g. silica gel)	To measure water content, accurate to within 1 % of gas volume
10	Thermometer for temperature measurement in duct	Thermocouple, temperature probe, equivalent	Accurate to within ± 1 % of absolute temperature
11	Instrument for measuring effective static pressure in duct	Liquid manometer, equivalent	Accurate to within ± 0,1 % of absolute pressure in duct
12	Sensitive differential pressure instrument connected to a Pitot tube (see part number 13)	Inclined liquid manometer, equivalent	Manometer capable of being read to within 5 Pa
13	Gas velocity measuring device	One of the Pitot tubes recommended in ISO 3966; devices not included in ISO 3966 (e.g. type S Pitot tube) may also be considered, if calibrated against a standard Pitot tube	Calibration against a standard Pitot tube to within ± 1 % of velocity (also see annex D)
14	Instrument for measuring the humidity of gases in duct	Condenser, wet and dry bulb, temperature dryer	To measure water content of duct gas to within ± 1 % of gas volume
15	Thermometer for temperature measurement at gas metering device	Thermometer, equivalent	Accurate to within ± 1 % of absolute temperature
16	Instrument for measuring effective static pressure at gas metering device	Liquid manometer, equivalent	Accurate to within ± 0,1 % of absolute pressure in gas metering device
17	Sensitive differential pressure instrument connected to sampling flow rate measuring device (Method I)	Inclined liquid manometer, equivalent	Manometer capable of being read to within ± 4 % of the reading
18	Barometer for measuring local atmospheric pressure		Accurate to within ± 300 Pa
19	Device for recovering any particles which are retained in entry nozzle or probe tube	Means should be provided to recover all matter deposited in entry nozzle and probe tube	Method employed shall not scratch internal surface
20	Containers for transporting the particulate matter	Containers shall be capable of being sealed; when particulate matter and containers are to be weighed together, containers should be of lightweight construction and capable of withstanding drying temperature	Collected particulate matter should not be less than 0,3 % of the mass of container to be weighed, unless use is made of a compensating balance capable of weighing to within ± 1 % of particulate mass or to the nearest 0,1 mg
21	Filter supports and/or filter-housings		Same specification as for part number 20, substituting "support" or "housing" for container
22	Timing device	Timing device shall be fitted with a start and stop mechanism	Timing device shall read to 1 s
23	Accessory particle separators	Cyclone, microcyclone, cloth filter bag, etc.	
24	Provision for heating or cooling probe tube, particle separator and sampling flow rate measuring device (Method I)		
25	Instrument for gas composition analysis	Any	Gas density accurate to within ± 2 %

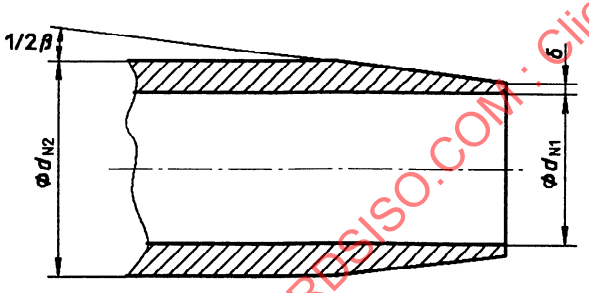
Part number	Part	Design	Specification
26	Balance	Compensating balances are required where relatively small quantities of particles are to be weighed in containers (see part number 20)	Capable of weighing collected particulate matter to within ± 1 % or to the nearest 0,1 mg
27	Duct dimension measuring device	Calibrated rod, reliable drawings for very large ducts	Internal dimensions of duct or chimney shall be measured to within ± 1 % of linear dimension

8.3 Entry nozzle

The entry nozzle is that part of the equipment which first admits a sample of the gas to the sampling train. The nozzle shall be sharp-edged in principle, of a simple design, and shall not include encumbrances that might affect the equipment performance. An example of a sharp-edged, simple profile is given in figure 7. Other mechanically less vulnerable designs are permissible, provided that they comply with the accuracy requirements of this International Standard.

If δ/d_{N1} is greater than 0,05, the effective diameter (d_N) shall be calculated using the formula

$$d_N = \sqrt{\frac{(d_{N1} + \delta)^2 + d_{N1}^2}{2}}$$



β and δ may assume any value if $d_{N2}/d_{N1} \leq 1{,}1$
$\beta \leq 20°$ and $\delta/d_{N1} \leq 0{,}05$ if $d_{N2}/d_{N1} \geq 1{,}1$

Figure 7 — Example of shape of the nozzle (1)

The diameter of the nozzle at the entrance shall not be less than 4 mm. Any subsequent changes in bore diameter shall be tapered rather than stepped and joints shall be smooth, to prevent deposition. Any bends in this section shall have a minimum radius of 1,5 times the nozzle bore diameter. The internal surface shall be smooth and the nozzle made of material which allows smoothness to be maintained. The distance from nozzle tip to nozzle support shall be long enough to avoid flow disturbances which would affect the local gas flow. In normal circumstances this would be about three support diameters.

NOTES

1 No reduction should be made in the internal diameter over a distance of one diameter of the entry section.

2 It is usual for a range of nozzles with different internal diameters to be supplied with the equipment, so that samples can be withdrawn from gas streams flowing at a wide range of velocities.

8.4 Probe tube

The probe tube is that part of the equipment which enables the entry nozzle to be placed within the duct or chimney in order that a sample of gas may be taken. It usually connects the various items of equipment, such as the entry nozzle, filter, water separator. Any part of the probe tube that is within the duct shall be rigid.

The probe tube shall be fitted with a pointer or other device to indicate the direction in which the entry nozzle is pointing.

All internal parts of the probe tube up to and including the filter shall be smooth and well polished, and the number of joints shall be kept to a minimum. Provisions shall be made, in this tube section, for recovering any solids deposited in the probe tube.

Provisions shall be made, if necessary, for heating or cooling of the probe tube without impeding ease of handling, to prevent any condensation (water vapour, sulfuric acid vapour) between nozzle and particle separators (or gas metering devices, where applicable).

8.5 Particle separators

In this International Standard, the particle separator that acts as the final filter in relation to the particles suspended in the gas sample is referred to as the main particle separator, even if it is the only separator. The other separators (cloth filter bag, cyclone etc.) are used to reduce the burden on the main filter.

The main particle separator shall contain a filter medium, suitable for the collection and retention of the particulate sample with an efficiency of ⩾ 98 %

for particles of diameter 0,3 µm at 20 °C (e.g. dioctylphtalate or equivalent test material). Note that the given maximum gas flow through a filter relevant to the filter efficiency shall not be exceeded (this may dictate filter size).

Filters with the most suitable properties for this purpose are either flat or thimble (fibre) filters. Fibre-packed filters are less well defined in their particle retention efficiency, depending on the fibre diameter and the method of packing. If they are used, the fibres shall be sufficiently fine and be packed carefully (avoiding channel formation) to a density such that the requirements given in the preceding paragraph are fulfilled. The retention efficiency of fibre-packed filters shall be checked against a flat (fibre) filter of known efficiency.

The filter support shall be designed in such a way that any deterioration of the filter during its removal from the support can be prevented.

During transportation, the loaded filters should be handled to avoid any loss of material and/or moisture absorption prior to weighing.

Special cases (e.g. soluble or metal-free materials for microscopic or chemical analysis) may require special filter materials. Soda glass fibre or other material likely to suffer attack by corrosive gases or solids shall not be used. Silica, borosilicate or aluminosilicate fibres are generally suitable.

The particle separator can be either inserted bodily into the duct or mounted externally to the duct. In the latter case, give consideration to heating the separators, to avoid any condensation. In the former case, the dimensions of the separator in relation to the nozzle tip distance shall be selected so that the gas stream at the nozzle entrance is not affected.

The nozzle, probe tube and particle separator are to be designed so that the particulate matter that has deposited upstream of the filter medium can be collected easily and quantitatively.

9 Advance preparations

9.1 General

Before carrying out any measurements, the purpose of the sampling and the sampling procedures shall be discussed with the plant personnel concerned. The nature of the plant process, e.g. steady state or cyclic, can affect the sampling programme. If the process can be performed in a steady state, it is important that, during the sampling, the process is conducted as nearly as possible under steady operating conditions.

Initially carry out a preliminary survey of the plant to enable the selection of the best sampling location (see 9.2) and the required number and pattern of the sampling points (see 9.3). This influences the positions of the access ports (see 9.4) and the position of a working platform (see 9.5).

From the information gathered, select the test equipment (see 9.6) and plan the test procedures. Discuss with plant management which provisions are available or still have to be provided. Any requirements concerning the avoidance of explosion and fire risks, the availability of suitable connections to the power supply and the compressed air system shall be observed. All safety requirements shall be assessed (see page 1 of this International Standard) and suitable procedures determined and followed.

A check on the suitability of the selected sampling position shall precede the proper sampling (see 9.7).

Dates, starting times, duration of survey and sampling periods, as well as plant operating conditions during these periods, shall be agreed upon with the plant management.

9.2 Selection of a suitable sampling location

The sampling location shall be situated in a length of straight duct with constant shape and constant cross-sectional area, preferably vertical, and downstream as far as practicable from any obstruction which may cause a disturbance and produce a change in the direction of flow (e.g. a bend, a fan or a partially closed damper).

To ensure a sufficiently homogeneous gas velocity distribution in the sampling plane, this section of straight duct should be at least seven hydraulic diameters long. Over the length of the straight section, locate the sampling plane at a distance of five hydraulic diameters from the inlet. If the sampling plane is to be located in a chimney discharging to the open air, the distance to the chimney top should also be five hydraulic diameters (making a straight length of ten hydraulic diameters). Choose a section where the distribution of particles can be expected to be reasonably uniform. Prior to sampling, ensure that the gas flow conditions meet the criteria described in 10.4.

If sampling in horizontal ducts is unavoidable, there are practical advantages in having access ports situated on top of a duct and due account shall be taken of any deposits at the bottom of the duct.

In practice, a straight duct length of seven hydraulic diameters will often be non-existent where ducts are wide. Selecting sampling planes here would not meet the above recommendation of minimum straight duct length. Under adverse gas flow and particulate stratification conditions this could lead to an unacceptable increase of inaccuracy in the results. Under favourable conditions, all other requirements of this International Standard shall be

followed to obtain the next best attainable accuracy of results. In this case, see annex E for recommendations.

9.3 Minimum number and location of sampling points

The minimum number of sampling points is dictated by the dimensions of the measuring plane. In general, this number increases as the dimensions increase.

Tables 4 and 5 give the minimum number of sampling points to be used for circular and rectangular ducts respectively. The sampling points to be used shall be located at the centre of equal areas in the sampling plane (see annex B).

Sampling points shall not be located within 3% of the sampling line length (if d or $l > 1$ m) or 3 cm (if d or $l < 1$ m) from the inner duct wall. Choose the inner edge of this area when calculations result in sampling point positions within this area. This may arise when selecting more than the minimum numbers of sampling points presented in tables 4 and 5, for example in cases of unusual duct shape or adverse flow conditions.

9.4 Size and position of access ports

Ports shall be provided for access to the sampling points selected in accordance with 9.3. The port dimensions depend on the dimensions of the related sampling equipment and should offer ample space for its insertion or removal.

See 9.2 for the position of access ports on horizontal ducts.

A second port may be required downstream of the sampling plane, if it is necessary to return sampled gas to the duct because of insufficient fan capacity or a toxicity hazard if vented.

9.5 Working platform

SAFETY PRECAUTIONS — The permanent or temporary platform shall have an adequate working area and shall be provided with 0,5 m **and** 1 m **high handrails, removable chains across the top of ladders and** 0,25 m **vertical base boards.**

The platforms shall preferably be positioned relative to the access ports, in such a way that the handrail will be clear of the apparatus to be used. The platform should be free from obstructions that would hamper insertion or removal of the sampling equipment. As a guide only, the platform surface area for ducts and chimneys should not normally be less than 5 m^2 and have a minimum breadth of 1 m or 2 m, depending on the duct diameter.

Provisions shall be made for any necessary services, such as compressed air, water or electricity, to suit the particular type of apparatus to be used.

Hoists for raising and lowering of equipment and also artificial lighting may be necessary.

If the platform is exposed to weather, suitable protection shall be considered for personnel and equipment. Electrical sockets, plugs and equipment shall be waterproof if they are to be exposed to bad weather.

Table 4 — Minimum number of sampling points for circular ducts

Range of sampling plane areas m^2	Range of duct diameters m	Minimum number of sampling lines (diameters)	Minimum number of sampling points per diameter: central-point		Minimum number of sampling points per plane: central-point	
			included	excluded	included	excluded
< 0,09	< 0,35	—	1[1)]	—	1[1)]	—
0,09 to 0,38	0,35 to 0,70	2	3	2	5	4
0,38 to 0,79	0,70 to 1,00	2	5	4	9	8
0,79 to 3,14	1,00 to 2,00	2	7	6	13	12
> 3,14	> 2,00	2	9	8	17	16

1) Using only one sampling point may give rise to errors greater than those specified in clause 14.

Table 5 — Minimum number of sampling points for rectangular ducts

Range of sampling plane areas m^2	Minimum number of side divisions[1)]	Minimum number of sampling points
< 0,09	—	1[2)]
0,09 to 0,38	2	4
0,38 to 1,50	3	9
> 1,50	4	16

1) Other side divisions may be necessary, for example if the longest duct side length is more than twice the length of the shortest side (see B.3).

2) Using only one sampling point may give rise to errors greater than those specified in clause 14.

9.6 Selection of apparatus

This will depend upon the type of solids that it is required to measure and also on the local circumstances at the plant. Take the following factors into account.

a) The likely concentration of solids.

b) The likely range of particle size.

c) The temperature of the duct gases in relation to either their acid or water dew point, as appropriate.

d) The likely fluctuations in the moisture content of the duct gas. If the water vapour concentration in the duct gas is likely to vary by more than ± 5 % (V/V) of the gas volume during the sampling period, the temperature of the gas sample shall be kept high enough to prevent condensation in the sampling train including the gas metering device.

e) The chemical composition of the flue gases, in relation to the materials from which the apparatus is constructed.

f) The highest temperature that certain types of apparatus can safely withstand.

g) The internal dimensions of the duct, in relation to the dimensions of the part of equipment that will be within the duct: the projected area of the part shall not exceed 10 % of the sampling plane area.

h) The velocity range of the duct gases.

i) The static pressure in the duct.

j) The likely hazard to operators.

Take adequate measures to avoid condensation of water, sulfuric acid, or other vapour within the apparatus, specifically between the nozzle and separator, or in the gas flow measuring device, if applicable. The temperature at any point in this section, probe tube and separator included, shall be at least 15 °C above the highest dew-point of the gas mixture. Where necessary, utilize a heating device.

9.7 Check on the suitability of the selected sampling position

To ensure that the sampling location has been suitably selected, so that the duct gas conditions in the sampling plane meet the stated requirements, perform a velocity and temperature survey in the sampling plane as described in 10.4.

NOTE 3 Normally, this survey is carried out prior to sampling, when all the necessary provisions and preparations for sampling have been made. However, this check can also be made in advance following the same procedure.

10 Preparatory work before sampling

10.1 Preparation of equipment

Before the operators move to the working platform, prepare the equipment in a clean working environment, either on-site or beforehand. Check any fans, pressure or temperature measuring instruments, rubber or plastics tubing, or any other accessories to ensure that they are in good condition. Check the sampling and Pitot tubes to ensure internal and external cleanliness.

Dry the filter (including the filter support, housing or container, where applicable) by heating in an oven to a temperature of 110 °C, cool in a desiccator, and weigh to constant weight before sampling. Use blank filters in the conditioning and weighing processes, in order to enable correction for varying conditions of temperature and moisture content of the ambient air. The filter material shall be compatible with the filtration temperature. If the fibre material might lose some mass on heating to the duct gas temperature, heat the filter to just above this temperature (10 K) prior to the final weighing to constant weight.

Take all weighed items to the working platform in clean, closed transport containers.

Calibrate the parts of the equipment that require it prior to use (see annex D), for example gas velocity, flow and volume measuring devices, gauges, etc.

10.2 Assembly and mounting of equipment

Where an (inclined) liquid manometer is used, set it up securely either on a level platform or by clamping it to a firm girder or rail.

Inspect the Pitot tube before use to check that all holes are clear of obstructions. Tape the connecting tubes from this equipment to the gauge at intervals, to avoid false readings due to unequal temperatures. Check the assembly for absence of leaks as follows. (See annex C.)

Prepare the sampling apparatus for use and check it thoroughly for leaks, in either of two ways. If a gas meter is used, block off the probe entrance with a plug or bung and operate the exhauster to create a reduced pressure of 50 kPa. Using the gas meter, measure any ingress of air into the assembled apparatus. Alternatively, for all other cases, also block off the probe entrance and create a reduced pressure of 50 kPa. Block off the other end of the train (e.g. by shutting the stop valve) and note any increase in the pressure. Calculate the corresponding leakage flow rate. Leaks shall be less than 1 % of the volumetric sample flow rate.

Place the apparatus adjacent to the access port, so that it is immediately available when the sampling nozzle size has finally been selected. Securely fix any manometers and gauges associated with the apparatus in convenient positions and connect them to the sampling apparatus.

10.3 Area measurement

Measure the internal dimensions of the duct to within $\pm$ 1 % of the linear dimension, using the duct dimension device described in table 3 (part number 27). Calculate the cross-sectional area available for flow (allowing for deposits and irregularities) from the measurements obtained. Neither the gas velocity measuring equipment nor the probe with nozzle shall be used for this purpose. If the cross-sectional area is derived from drawings, check whether the drawings are a true representation of the duct. Allow for deposits.

10.4 Preliminary velocity and temperature survey

Before any sampling is undertaken, carry out a preliminary survey. Measure the temperature and differential pressure of the Pitot static tube (or gas velocity if a different instrument is used), at ten approximately equally spaced points along each selected sampling line, conveniently including all sampling point positions, but excluding the region within 3 % of the effective duct diameter and at least 3 cm from the wall. The measurements at the sampling point positions can be used to calculate the sample extraction flows, if the gas flow in the duct is steady.

More velocity measurement points than sampling points are required for two reasons: to judge the suitability of the sampling position and to accurately calculate the total gas flow and particulate mass flow rate in the duct after sampling.

NOTE 4 Highest accuracy could be obtained when following ISO 3966 which covers fluid flow measurements in closed circuits. However, the requirements of ISO 3966 are frequently impossible to meet in duct situations.

Conduct this survey when the plant is operating under conditions that will be adhered to during the test, in order to determine if the sampling position is suitable and if the conditions in the duct are satisfactory for isokinetic sampling. Such conditions include the following:

a) angle of gas flow $\leqslant$ 15°, with regard to duct axis;

b) no local negative gas flow;

c) minimum velocity depending on the method used (for Pitot tubes a differential pressure $\geqslant$ 5 Pa);

d) ratio of the highest to lowest local gas velocities $\leqslant$ 3:1;

e) temperature, in kelvins, at any point $\leqslant \pm$ 5 % from the mean temperature, in kelvins.

If the gas condition requirements in items a) to e) are not met, seek another sampling position. Otherwise, the measurement of the particulate concentration and mass flow will not be in compliance with this International Standard.

11 Sampling procedure

11.1 Gas velocity and temperature measurement

Prior to sampling, carry out a preliminary survey using velocity and temperature measurements as described in 10.4. If these measurements have been made during a preliminary survey at an earlier stage, repeat the measurements prior to the actual sampling, in order to confirm that no unexpected changes in the flow or temperature patterns have occurred since the preliminary survey.

11.2 Number and location of sampling points

Take samples at the points selected in accordance with 9.3. Determine the locations of the sampling points from the internal dimensions of the duct and from annex B. Mark the distances from the sampling points to the inner wall of the access port with heat-resistant marking on both the gas velocity

measuring device and the sampling probe, allowing for duct wall thickness and for access port fitting.

If flow conditions are quite steady (variations in velocity < 5 %), isokinetic sample flow rates may be based upon temperature and gas velocity measurements at the sampling points prior to sampling. These measurements may be advantageously incorporated in the preliminary survey described in 11.1. The nozzle size is selected accordingly.

Check the steadiness of the flow as soon as sampling has been completed (see 11.4.4).

Where flow conditions are less steady (variation in velocity < 10 %), isokinetic sampling could be maintained by sampling the gas at each point while measuring the gas velocity at a reference point, assuming that the relative variations of the local gas velocities are identical. However, check this assumption for each process.

Where large variations (> 10 %) in duct flow conditions occur, ensure that sampling is isokinetic by measuring the gas velocity at the sampling point while sampling the gas. If variations occur, adjust the sample flow rate accordingly. In this case, for example, use can be made of a combined Pitot tube and probe. When using this combination, the probe nozzle and the Pitot tube head shall be placed sufficiently far apart to avoid mutual disturbance of the gas velocity measurement and the extraction. Calibrate the Pitot tube while it is attached to the sampler (see annex D).

11.3 Duration of sampling

The sampling duration at each sampling point shall be not less than 3 min, in order to minimize timing and flow adjustment errors.

The choice of total duration of sampling is dependent upon

a) ensuring that an adequate quantity of material is collected for weighing (see clause 10);

b) avoiding the collection of an excessive quantity of material that could interfere with the efficiency of separation or the operation of the sampling apparatus;

c) whether cumulative or incremental sampling is undertaken;

d) the number of sampling points;

e) the continuity of plant operation, or the duration of operating cycles.

Select the longest practicable sampling period consistent with these considerations.

11.4 Sampling

11.4.1 General

When the probe is inserted in the duct or withdrawn from it, it is imperative that no particles pass into or drop from the nozzle opening. To prevent the gain or loss of particles, the following requirements must be met.

a) No gas flow through the sampling train is permitted and the stop valve shall be closed;

b) The probe shall be held so that the nozzle axis is at a right angle to the direction of the duct gas flow, but the nozzle shall not point in a downward direction.

c) The probe shall always be handled with great care, to minimize disturbance of collected particulate matter within the apparatus and to avoid contact with any deposits within the duct or the access port.

With the correct nozzle fitted and with the control valve tightly closed, insert the probe tube [following the requirements mentioned in items a) to c)] and where necessary the velocity measuring device through the access port until the nozzle (and the velocity sensing head) is located at the first sampling point (to within 2 % of the internal duct dimension or 1 cm, whichever is larger).

Allow the apparatus within the duct to attain the temperature of the duct gases. Switch on any heaters for the apparatus and check that they are functioning correctly. If necessary, speed up this procedure by heating the relevant parts beforehand.

Start the exhauster and turn the probe tube until the nozzle is facing directly upstream (to within about 10 °). Secure the probe tube in that position. Start the timing device and open the control valve immediately. Then adjust the control valve to give the required flow reading as calculated according to nozzle size, gas velocity, etc. (see 13.3) using, for example, a nomograph or calculator. Adjust the control valve as necessary throughout the sampling period to maintain isokinetic sampling. The velocity of the gas drawn from the entry nozzle shall be kept within ± 10 % of the duct gas velocity at the measuring point.

Where the sample gas volume is derived from a differential pressure flow-meter and the sampling time, the meter shall be read frequently enough to determine this volume with sufficient accuracy.

Follow one of the alternative procedures described in 11.4.2 or 11.4.3, then proceed as described in 11.4.4.

11.4.2 Cumulative sampling (3.3)

After the first sample has been taken, but without removing the collected material, quickly move the probe tube to reposition the nozzle at the second sampling point, within the tolerances stated in 11.4.1. Immediately adjust the control valve to the required flow reading which is appropriate to the second sampling point. Then continue sampling as described in 11.4.1 and repeat the procedures until samples have been taken at all points on the first sampling line. Close the control valve, stop the timing device and rotate the probe so that the nozzle is at a right angle to the gas flow [see the requirements in 11.4.1, a) to c)]. Remove the probe tube from the access port and reposition it on the next sampling line (see 11.4.3), and repeat these procedures until all the samples have been collected.

Where the sampling points represent equal areas, the sampling period at each point has to be similar.

11.4.3 Incremental sampling (3.8)

If the separator is fitted on the probe tube within the duct, close the control valve and stop the timing device after the first sample has been taken. Then withdraw the probe tube (see 11.4.2), remove the sample collection container(s) and recover possible deposits from the inside of the probe. After replacement with new container(s), follow the procedure which is described in 11.4.1 for the next sampling point.

If the separator is fitted externally, the probe tube may also need to be withdrawn for these operations, to prevent loss of internal probe deposits.

Repeat the procedures until all the separate samples have been taken from each sampling point.

11.4.4 Repeat gas velocity and temperature readings

If velocity measurement and gas sampling have not been carried out simultaneously, repeat the readings of gas velocity and temperature at each sampling point (see 11.2) as soon as sampling at all sampling points has been completed. If the sum of the gas velocities differs by more than $\pm$ 5 % from the sum of the original velocities of 11.2, the test result shall not be regarded as sufficiently accurate.

Check if isokinetic conditions have been fulfilled (to within $\pm$ 10 %) by comparing the calculated extracted flow and the measured sample flow rate converted to actual duct conditions, or by comparing the measured gas velocity at the sampling point and the calculated nozzle velocity at actual duct conditions derived from the measured sample flow (see 13.3).

If it turns out that isokinetic conditions have not been achieved, discard the measurement, investigate the causes and repeat the measurement.

For accurate calculations of the total gas flow and particulate mass flow rate in the duct, repeat the velocity measurements across the duct as described in 10.4.

11.5 Repeat samples

When repeat measurements of the particulate concentration are required, repeat the whole procedure of 11.4 under comparable plant conditions and as soon as is practicable.

If this second sampling immediately follows the first, the gas velocity and temperature readings taken in 11.4.4 may be used as the initial readings for the second set of samples.

12 Weighing

Transport the parts of the apparatus containing the collected samples in clean, enclosed transport containers for weighing. Ensure that all items to be weighed have been carefully cleaned externally to remove any superficial material.

Ascertain the mass of any solids deposited on internal surfaces of the apparatus as far as practicable, and add it to the mass of the particles collected. If necessary, clean the internal surfaces ultrasonically or rinse with an appropriate liquid (e.g. acetone), and brush to remove adhering particles. Transfer the washings to a tared beaker and evaporate to dryness at ambient temperature and pressure. Dry the residue and weigh under the same conditions as the particulate matter collected on the filter.

Dry the loaded filter (including the filter support, housing or container) with the added particulate matter from the internal surfaces, cool it in a desiccator to room temperature and weigh to constant weight under the same conditions as before sampling.

Take care to ensure that the collected particulate matter is not affected in any other way by the drying temperature.

The overall accuracy of the particulate concentration measurement under ideal conditions (representative sampling) is about 10 % (see clause 14). This is based on the assumption that the weighing inaccuracy is better than 2 %. To achieve this, an adequate quantity of particulate matter has to be collected. Considering an error of 1 mg per weighing, and considering the fact that the collected amount is calculated from the difference of two weighings, an adequate quantity amounts to about 100 mg. The actual quantity that is collected depends on the

concentration, sampling time and pump capacity. For low concentrations, an increase of the sampling time and pump capacity will be needed to collect an adequate quantity. Otherwise, improvement of the weighing procedure is necessary to obtain a weighing error < 1 mg.

13 Method of calculation

13.1 General

In the subclauses of this clause, typical calculations are given in the sequence of the diagrams in figures 5 and 6. The numbers in parenthesis in the text of this clause refer to the corresponding items in the diagrams in these figures. The symbols and subscripts used in the equations are explained in clause 4.

13.2 Duct gas flow

To calculate the gas velocity at a local point (8) determine the gas density (7) in addition to the differential pressure (1). Calculate the average gas velocity from the measurements at all points. Calculate the duct gas flow (9) from the product of the average gas velocity (8) and the sampling plane area (2).

The density of gases under standard conditions, ρ_n, of dry gas is as follows:

$$\rho_n = \sum_{i=1}^{N} r_{n,i} \times \rho_{n,i} \quad \ldots (1)$$

or

$$\rho_n = \sum_{i=1}^{N} r_{n,i} \times \frac{M_i}{V_{m,n,i}} \quad \ldots (2)$$

The density of a single gaseous component in a gas mixture under standard conditions can be calculated by dividing the molar mass by the molar volume concerned under standard conditions. Normally, 22,4 m^3/kmol is used for the molar volume.

The water vapour concentration, f, of a gas is found using one of the methods given in table 3 (part number 14).

The density of moist gases at 273 K and 101,3 kPa, ρ'_n, can be calculated as follows:

$$\rho'_n = \frac{\rho_n + f_n}{1 + \frac{f_n}{0{,}804}} \quad \ldots (3)$$

or

$$\rho'_n = \frac{p_w}{p_n} \times 0{,}804 + \left(1 - \frac{p_w}{p_n}\right)\rho_n \quad \ldots (4)$$

where 0,804 is the ideal density of water vapour, in kilograms per cubic metre, under standard conditions.

The density of the gas in the duct (under operating conditions) can be calculated, when the following quantities are also known:

— ambient pressure, p_{am}, at the altitude of the sampling plane;

— effective pressure, p_e, i.e. the difference between the pressure in the duct and the ambient pressure at the altitude of the sampling plane;

— average gas temperature in the sampling plane, Θ_a.

The density under actual conditions (7) is then

$$\rho'_a = \rho'_n \times \frac{T_n}{p_n} \times \frac{p_a}{T_a} =$$

$$= \rho'_n \times \frac{T_n}{p_n} \times \frac{p_{am} + p_{e,a}}{T_n + \Theta_a} \quad \ldots (5)$$

When using a standard Pitot tube, the gas velocity; v'_a, at a sampling point (8) is expressed as

$$v'_a = \sqrt{\frac{2}{\rho'_a}} \times \sqrt{\Delta p_{Pt}} \quad \ldots (6)$$

When using other types of Pitot tubes, a calibration factor, K_{Pt}, shall be introduced. Then the equation changes as follows:

$$v'_a = K_{Pt} \times \sqrt{\frac{2}{\rho'_a}} \times \sqrt{\Delta p_{Pt}} \quad \ldots (7)$$

where $K_{Pt} \neq 1$.

Both equations (6) and (7) can be used for gas flow rates of up to 50 m/s.

The average gas velocity in the sampling plane, $\bar{v}'$, is calculated using equation (8) only if all local velocities correspond to local areas.

$$\bar{v}' = \frac{1}{N} \sum_{i=1}^{N} v'_i \quad \ldots (8)$$

The duct gas flow (9), q'_{V_a}, is calculated as follows:

$$q'_{V_a} = A\bar{v}' \times 3\,600 \quad \ldots (9)$$

13.3 Sample gas flow

The condition for isokinetic sampling at any sampling point is

$$v'_a = v'_N \quad \ldots (10)$$

The gas velocity at the sampling points amounts to

$$v'_a = K_{Pt} \times \sqrt{\frac{2}{\rho'_a}} \times \sqrt{\Delta p_{Pt}} \quad \ldots (11)$$

Where the moist sample gas flow rate is measured (see figure 6) by, for example, an orifice, the velocity, v'_N, in the nozzle opening amounts to

$$v'_N = \frac{1}{a} \times \frac{1}{3\,600} \times q'_{V_N} = \frac{1}{a} \times K_o \times \sqrt{\frac{2}{\rho'_o}} \times \sqrt{\Delta p_o} \times \frac{p_{am} + p_{e,o}}{p_{am} + p_{e,a}} \times \frac{T_n + \Theta_a}{T_n + \Theta_o} \quad \ldots (12)$$

From equations (10) to (12) it follows that

$$\Delta p_o = \Delta p_{Pt} \times \frac{\rho'_o}{\rho'_a} \times \left(a \times \frac{K_{Pt}}{K_o} \times \frac{p_{am} + p_{e,a}}{p_{am} + p_{e,o}} \times \frac{T_n + \Theta_o}{T_n + \Theta_a} \right)^2 \quad \ldots (13)$$

The sampling rate is set at each sampling point by observing the value of the Pitot tube differential pressure, Δp_{Pt}, calculating the value of the pressure drops across the orifice meter, Δp_o, from equation (13), and adjusting the apparatus so that Δp_o is obtained (12).

Where the dried gas sample flow rate is measured (see figure 5) by another device, e.g. a rotameter, the velocity in the nozzle opening amounts to

$$v'_N = \frac{1}{a} \times \frac{1}{3\,600} \times q'_{V_N} = \frac{1}{a} \times \frac{1}{3\,600} \times q_{V_g} \times \frac{p_{am} + p_{e,g}}{p_{am} + p_{e,a}} \times \frac{T_n + \Theta_a}{T_N + \Theta_g} \times \left(1 + \frac{f_n}{0{,}804} \right) \quad \ldots (14)$$

From equations (10), (11) and (14) it follows that

$$q_{V_g} = \sqrt{\Delta p_{Pt}} \times 3\,600\, a \times K_{Pt} \times \sqrt{\frac{2}{\rho'_a}} \times \frac{p_{am} + p_{e,a}}{p_{am} + p_{e,g}} \times \frac{T_n + \Theta_g}{T_n + \Theta_a} \times \frac{1}{1 + \frac{f_n}{0{,}804}} \quad \ldots (15)$$

Here, the sampling rate is set at each point by observing the Pitot tube pressure drop, Δp_{Pt}, and performing calculation (15). The gas volumetric flow rate through the rotameter, q_{V_g}, is then adjusted to the calculated value (12). The sampling is isokinetic when this value is reached.

The sampling will be isokinetic if, in practice, the calculated values for Δp_o or q_{V_g} [equations (13) and (15)] can be achieved in the sampling system. If these values cannot be achieved, the degree to which the sampling is not isokinetic can be expressed by the ratio v'_N/v'_a or $q_{V_N}/3\,600 a v'_a$.

Isokinetic sampling is the condition where $v'_N/v'_a = 1{,}0$.

Sampling is to be conducted within the following limits (see 11.4.1):

$$0{,}9 < \frac{v'_N}{v'_a} < 1{,}1 \quad \ldots (16)$$

In cases where the value of q'_{V_N} can be obtained independently of the system flow-rate monitoring device (e.g. by using a dry gas meter and timer), a calculation of the fraction can provide additional information about the quality of the sampling.

13.4 Sample gas volume

The sample gas volume may be measured by a gas flow-meter (Method I, table 3, part number 4) or an integrating gas volume meter (Method II, table 3, part number 7).

In situation I, the moist gas sample volume, V'_o, amounts to

$$V'_o = t q'_{V_o} = 3\,600 t K_o \times \sqrt{\frac{2}{\rho'_o}} \times \sqrt{\Delta p_o} \quad \ldots (17)$$

In situation II, the dry gas sample volume (15) amounts to

$$V_g = \text{reading}_{end} - \text{reading}_{start} \quad \ldots (18)$$

13.5 Particulate concentration

For the particulate concentration of an integral gas sample per sampling plane (one filtration) (22),

— expressed per cubic metre of dry gas mixture under standard conditions (22), the following applies:

$$c_n = \frac{m}{V_{g,n}} \quad \ldots (19)$$

— expressed per cubic metre of moist gas sample under standard conditions, the following applies:

$$c'_n = \frac{m}{V'_{g,n}} \quad \ldots (20)$$

— expressed per cubic metre of moist gas mixture under operating conditions, the following applies:

$$c'_a = \frac{m}{V'_{g,a}} \quad \ldots (21)$$

For the particulate concentration, for more than one gas sample (and filtration) per sampling plane,

— expressed per cubic metre of dry gas mixture under standard conditions, the following applies:

$$\bar{c}_n = \frac{\sum_{i=1}^{N} c_{n,i} \cdot v_{n,i}}{\sum_{i=1}^{N} v_{n,i}} \quad \ldots (22)$$

where

$$c_{n,i} = \frac{m_i}{V_{g,n,i}}$$

— expressed per cubic metre of moist gas mixture under standard conditions, the following applies:

$$\bar{c}'_n = \frac{\sum_{i=1}^{N} c'_{n,i} \cdot v'_{n,i}}{\sum_{i=1}^{N} v'_{n,i}} \quad \ldots (23)$$

where

$$c'_{n,i} = \frac{m_i}{V'_{g,n,i}}$$

— expressed per cubic metres of gas mixture under operating conditions, the following applies:

$$\bar{c}'_a = \frac{\sum_{i=1}^{N} c'_{a,i} \cdot v'_{a,i}}{\sum_{i=1}^{N} v'_{a,i}} \quad \ldots (24)$$

where

$$c'_{a,i} = \frac{m_i}{V'_{g,a,i}}$$

Where appropriate, refer the particulate concentration to a specified gas component concentration of the gas mixture, e.g. the carbon dioxide or oxygen concentration. To this end, the particulate concentration value is, when either carbon dioxide or oxygen is concerned, multiplied by the ratio

$$\frac{[CO_2]\text{selected}}{[CO_2]\text{measured}}$$

or

$$\frac{20{,}95 - [O_2]\text{selected}}{20{,}95 - [O_2]\text{measured}}$$

where 20,95 is the oxygen content of air, in percentage on volume basis.

When carrying out this calculation, it is important that the selected and measured gas component concentrations refer to the same gas conditions.

13.6 Particulate mass flow rate

The particulate mass flow rate (23) is calculated as the product of particulate concentration and duct gas volumetric flow:

$q_m = cq_V$, with cumulative ... (25)

$q_m = \bar{c}\bar{q}_V$, with incremental sampling ... (26)

The quantities of c and q_V shall always refer to the same gas conditions.

For an alternative calculation, see annex F.

14 Accuracy

Under ideal conditions in the duct, the inaccuracy of the method will be about ± 10 % of the particulate concentration. In practice, these conditions do not always exist as fluctuations may occur in gas flow and particulate concentration during sampling. In cases where samples are not completely representative, though still satisfying the requirements of this International Standard, the total inaccuracy of the method will be greater than ± 10 %. See annex A.

15 Test report

The results obtained by measurements and calculations made in accordance with this International Standard shall be summarized together with relevant information which shall include such items as are appropriate selected from the following.

a) A reference to this Internationl Standard.

b) Date, time and place of the measurements.

c) Conditions of the object to be measured:

- type of the source of generation;
- conditions in the source of generation during the measurements (plantload, throughput);
- sampling location;
- shape and size of the duct;
- number and positions of sampling points.

d) Conditions of the gas in the duct:

- pressure;
- temperature;
- water content;

- composition;
- density;
- velocity;
- flow rate.

e) Conditions of sampling:

- method of measuring particulate concentration (sampling method, suction nozzle, arrangement of particle collecting part and conditions for drying particulate matter);
- size, type and material of separator;
- suction nozzle diameter;
- suction flow rate for isokinetic sampling at each point;
- result of check on isokinetic sampling at each point;
- time required for sampling;
- sample gas volume;
- static-pressure at gas metering device;
- temperature at gas metering device;
- volume of gas drawn;
- particulate mass collected.

f) Particulate concentration.

g) Particulate mass flow rate.

Annex A
(normative)

Factors affecting the accuracy of the method

As stated in clause 14, the inaccuracy of this method for determination of the concentration of particulate matter is about ± 10 % under ideal conditions in the duct. This value was derived from estimates of the errors of the separate parts of the equipment used (see table 3) by treating these as random errors. It is valid provided all requirements of the method have been satisfied. In this respect, it is essential that due attention is given to the collected particulate matter: complete incorporation of deposits in the sampling train, a sufficient quantity of matter for weighing and prevention of artifact formation during the measuring process.

The inaccuracy mentioned will tend to increase when the composite sample departs from being completely representative. Some of the factors affecting the representativeness are discussed briefly in A.1 to A.6.

A.1 Location of sampling plane

A distance between sampling plane and upstream flow disturbance which is shorter than prescribed may increase the error in the measured concentration value. This depends on the type of disturbance, the maximum and minimum local gas velocities in the sampling plane and the size distribution of the particulate matter. For combustion installations, an estimated overall error of 20 % was reported, provided that minimum distances to upstream obstacles are maintained as described in annex E [6].

A.2 Number of sampling points

Generally, accuracy will be better with an increasing number of sampling points. However, increasing the number over 16 will not improve the accuracy. In this case, the accuracy could be improved by increasing the number of sampling lines (three instead of two) in circular ducts.

A.3 Sampling time

Longer sampling times may be desirable to moderate variations in the particulate concentration with time, thus decreasing the error.

A.4 Nozzle design

Using a nozzle according to 8.3 and figure 7, the deviation from an infinitely thin nozzle will be less than 5 % [1], assuming that all other equipment parts (Pitot static tube, probe, filter) are sufficiently remote from the nozzle opening to have no effect on the gas stream at the nozzle tip.

A.5 Nozzle alignment

If the gas is sampled isokinetically and the angle between the flow direction and the nozzle axis is not more than 15°, the deviation from an aligned nozzle will be less than 3,5 % [1].

A.6 Departure from isokinetic sampling

A 10 % discrepancy in gas velocity between the flow at the nozzle tip and the flow in the duct can cause a deviation of greater than 10 % in the value of the concentration measurement. This error, however, strongly depends on particle size and gas velocity [1, 4]. At a gas velocity of 20 m/s when all the particles are smaller than 3 µm, no appreciable error will occur at deviations from isokinetic conditions. Fluctuations of flow rates in a duct may be so strong that isokinetic sampling is prohibited. When the fluctuations are within a range of ± 50 % of the average flow rate, the error is less than ± 5 %; at larger fluctuations the error will increase rapidly.

The accuracy of the particulate flow rate determination is also affected by the error associated with the duct gas velocities. Under ideal flow conditions the error amounts to between 3 % and 5 %. The error may easily increase, due to non-parallel flow to the nozzle, large, rapid gas flow fluctuations, whirls in the ducts and the presence of droplets.

Quality assurance procedures [11] should be considered as a helpful aid in maintaining the best achievable accuracy.

Annex B
(normative)

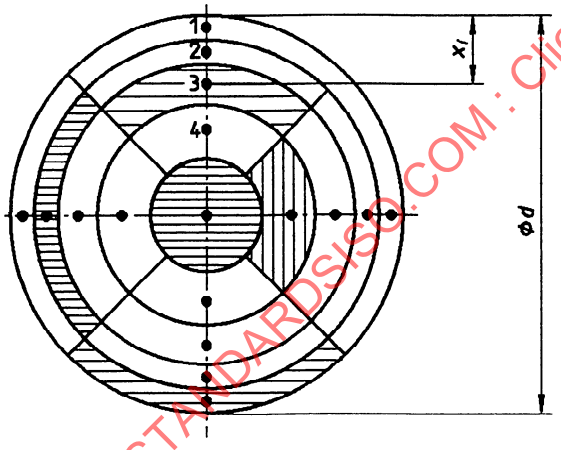
Methods and rules for determining the position of sampling points in circular and rectangular ducts

B.1 General rule for circular ducts

In the "general rule" applicable to circular ducts, the sampling plane is divided into equal areas, one of which is circular. The sampling points, one at the centre of each area, are located on two or more diameters (sampling lines), there being one point at the centre of the duct. See figure B.1.

The locations of the sampling points on each diameter are dependent on the number of sampling points on each diameter and also on the number of sampling diameters.

For circular ducts where two sampling lines (diameters) are sufficient, the distance of each sampling point from the duct wall may conveniently be expressed as $x_i = K_i d$.



The shaded positions are of equal area.

Figure B.1 — Sampling point positions in circular ducts — General rule (showing positions for ducts over 2 m in diameter)

Table B.1 gives values of K_i as a percentage, where n_d is the number of sampling points per sampling line (diameter) and i is the number of individual sampling points along the diameter.

Table B.1 — Values of K_i as a percentage — General rule for circular ducts

i \ n_d	3	5	7	9
1	11,3	5,9	4,0	3,0
2	50,0	21,1	13,3	9,8
3	88,7	50,0	26,0	17,8
4		78,9	50,0	29,0
5		94,1	74,0	50,0
6			86,7	71,0
7			96,0	82,2
8				90,2
9				97,0

For circular ducts where it is necessary to increase the number of sampling lines (diameters) or the number of sampling points, the general formula for calculating the distance, in metres, from the duct wall along the diameter, x_i, is

$$x_i = \frac{d}{2}\left[1 - \sqrt{\frac{(2n_r - 2i + 1)n_d + 1}{2n_r \cdot n_{dia} + 1}}\right] \quad \ldots (B.1)$$

where

i is the number of individual points along the diameter;

d is the diameter (length of sampling line), in metres.

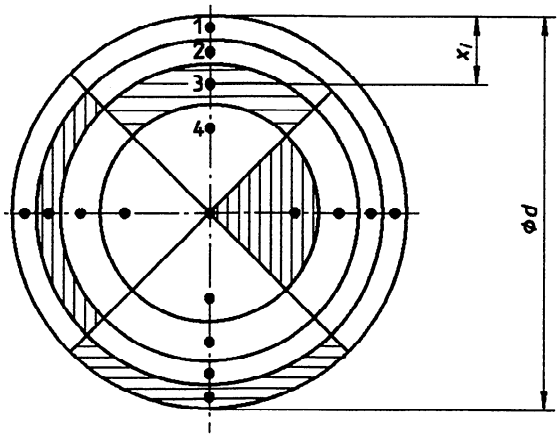
B.2 Tangential rule for circular ducts

In the "tangential rule" applicable to circular ducts, the sampling plane is divided into equal areas. The sampling points, one at the centre of each area, are located on two or more diameters (sampling lines), there being no sampling point at the centre of the duct. See figure B.2.

The locations of the sampling points on each diameter are dependent on the number of sampling points on each diameter but are independent of the number of sampling diameters.

For circular ducts where two sampling lines (diameters) are sufficient, the distance of each sampling point from the duct wall may conveniently be expressed as $x_i = K_i d$.

Table B.2 gives values of K_i as a percentage, where n_d is the number of sampling points per sampling line (diameter), and i is the number of individual sampling points along the diameter.



The shaded portions are of equal area.

Figure B.2 — Sampling point positions in circular ducts — Tangential rule (showing positions for ducts over 2 m in diameter)

Table B.2 — Values of K_i as a percentage — Tangential rule for circular ducts

i \ n_d	2	4	6	8
1	14,6	6,7	4,4	3,3
2	85,4	25,0	14,6	10,5
3		75,0	29,6	19,4
4		93,3	70,4	32,3
5			85,4	67,7
6			95,6	80,6
7				89,5
8				96,7

For circular ducts where it is necessary to increase the number of sampling lines (diameters) or the number of sampling points, the tangential formula for calculating the distance in metres, from the duct wall along the diameter, x_i, is

$$x_i = \frac{d}{2}\left[1 - \sqrt{\frac{1-(2i-1)}{2n_r}}\right] \quad \ldots (B.2)$$

where

i is the number of individual points along the diameter;

d is the diameter (length of sampling line), in metres.

This method is particularly useful for large ducts where it would be difficult to reach the centre of the duct.

B.3 Rule for rectangular (and square) ducts

In the rule applicable to rectangular ducts, including square ducts, the sampling plane is divided into equal areas by lines parallel to the sides of the duct, and a sampling point is located at the centre of each area. See figure B.3.

In general, both sides of the rectangular duct are divided into an equal number of parts, giving areas which have the same shape as the duct. The number of partial areas is thus the square of 1, 2, 3, etc. See figure B.3 a).

If the lengths of the sampling plane sides (l_1 and l_2, l_1 being greater than l_2) have a ratio $l_1/l_2 > 2$, side l_1 must be divided by a greater number than l_2 so that each of the smaller areas meets the criterium that the longest side shall not be more than twice the length of the shortest side. See figure B.3 b).

If the lengths of the sampling plane sides l_1 and l_2 are divided into n_1 and n_2 parts respectively, the number of sampling points will be $n_1 \cdot n_2$ and the smallest distance from a wall of the duct will be $l_1/2n_1$ and $l_2/2n_2$.

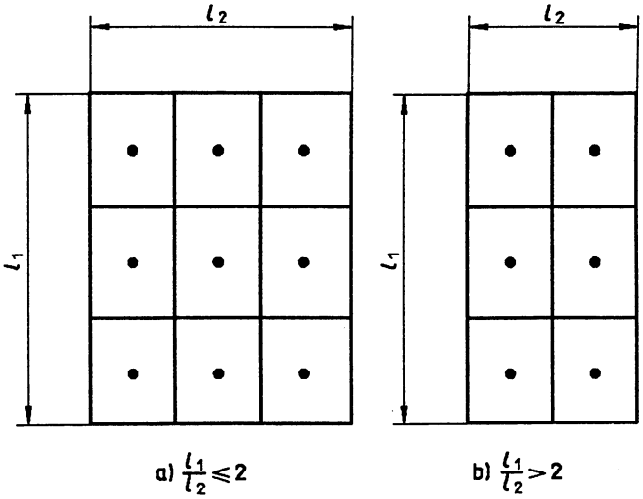


Figure B.3 — Illustrations of sampling point positions in rectangular (and square) ducts

Annex C
(normative)

Care and use of Pitot static tubes

C.1 General

The contents of this annex are supplementary to the requirements of ISO 3966, insofar as hot dusty gases present special difficulties when Pitot static tubes are used.

A Pitot static tube will not function correctly unless

a) the total pressure hole (the nozzle) and static pressure holes are in free and gas-tight communication with their respective nipples at the end of the probe stem;

b) the shape and dimensions of the Pitot tube head (that portion lying at right angles to the main stem) are maintained in accordance either with those described in ISO 3966, or with those that it possessed during calibration in appropriate conditions;

c) the head faces directly into the gas flow (within $\pm$ 10°);

d) the two lengths of tubing leading to the manometer are fastened together to obviate thermal errors;

e) the velocity pressure head is more than 5 Pa.

The function of a maintenance system is to ensure that these conditions are maintained during use and that the Pitot static tube will have a useful working life. It is recommended that the checks described in C.2 be carried out, as a routine measure, after each period of use. The results obtained during the period may then be relied upon and the Pitot static tube may be used with confidence on the next occasion. If the probe suffers damage or is exposed to unusually severe conditions (e.g. high duct gas temperature), it is essential that these checks be made before the Pitot static tube is used again.

C.2 Routine examination and maintenance

Examine the head of the Pitot static tube before and after use for any obvious signs of damage (e.g. dents or burrs) and ensure that the total pressure and static holes are unblocked.

Ensure that the head is straight and that it lies at right angles to the probe stem.

Before use, blow through the Pitot static tube, via the nipples, alternately blocking and opening the nozzle and static pressure holes.

It is essential that the whole apparatus, including connectors, joints and tubing, be checked periodically for leaks, particularly if any reading peculiarities are suspected. Although awkward to carry out, the best procedure is to seal the nozzle and static holes firmly and then to assemble the whole apparatus and immerse it in water whilst applying a low positive air pressure through the connecting tubing.

If any repairs are necessary, it is essential that they do not alter the original form of the Pitot static tube head or recalibration will be required. The test described in the preceding paragraph should be repeated if any repairs have been carried out.

C.3 Relation of Pitot head to gas flow direction

A standard Pitot static tube can provide an accurate measure of gas velocity provided that the head is towards, and within $\pm$ 10° of, the direction of gas flow. The Pitot tube pressure difference decreases markedly if misalignment exceeds 10°, until a sharply negative response occurs when the head is at 90° to the gas flow. This provides a simple method for estimating gas flow direction and may be used to test for the presence of swirling flow within the duct.