

INTERNATIONAL STANDARD

ISO
10780

First edition
1994-11-15

Stationary source emissions — Measurement of velocity and volume flowrate of gas streams in ducts

*Émissions de sources fixes — Mesurage de la vitesse et du débit-volume
des courants gazeux dans des conduites*



Reference number
ISO 10780:1994(E)

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International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

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 10780 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions*.

Annexes A and B form an integral part of this International Standard. Annexes C and D are for information only.

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Introduction

ISO/TC 146/SC 1 prepares International Standards for the determination of concentrations of pollutants in stationary source emissions. For the calculation of the emission rate, the volume flow of a gas stream has to be measured. This International Standard specifies methods for the determination of the velocity and the volume flowrate of gas streams in ducts and chimneys. It is based largely on ISO 3966:1977, ISO 4006:1977 and ISO 9096:1990. ISO 3966 and ISO 4006 specify methods for measuring the flow of process streams in closed conduits using type L Pitot static tubes. ISO 9096 specifies ways to measure velocity and mass flow when sampling for particles in gas streams in ducts and chimneys. This International Standard differs from ISO 3966 and ISO 4006 in allowing the use of the type S Pitot tube (a device not mentioned in ISO 3966) as well as the type L. It differs from ISO 9096 in that it provides considerably more information concerning the construction and use of the Pitot tubes commonly used to measure the velocity and volume flowrate of gas streams in ducts and chimneys.

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Stationary source emissions — Measurement of velocity and volume flowrate of gas streams in ducts

1 Scope

This International Standard specifies manual methods for determining the velocity and volume flowrate of gas streams in ducts, stacks and chimneys vented to the atmosphere. It specifies the use of two types of Pitot tubes, type L and type S, for determining the velocity and the volume flowrate, and recommends sampling conditions for which each type of Pitot tube is preferred.

The use of other types of Pitot tubes is permitted in accordance with this International Standard providing they meet the accuracy requirements in clause 10.

This International Standard applies to gas streams with essentially constant density, temperature, flowrate and pressure at the sampling points. It applies to situations where the Reynolds number of the gas stream as it flows around the Pitot tube is greater than 1,2, the pressure differential across the Pitot tube orifices (ports) is greater than 5 Pa and the cross-sectional area of the duct at the sampling point is at least 0,07 m². It specifies the technology and maintenance of Pitot tubes, the calculation of local velocities from measured differential pressures and the computation of volume flowrate by velocity integration. This International Standard assumes that the measurements are taken either at the same time that a pollutant sample is being collected or independently of actual sample collection; in the latter case, the purpose of the test might be to select the sampling location for collecting a pollutant sample or to calibrate an automated flow measuring instrument installed in the duct. Thus, this International Standard should be suitable as both a primary measurement (velocity and volume flowrate) and as an ancillary measurement (selection of sampling rate for pollutant sampling, calculation of pollutant emission rate, etc.).

If any of the requirements of this International Standard are not fulfilled, this method may still be applied

in special cases, but the uncertainty in the velocity and volume flowrate may be larger.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were 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 editions of the standards 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*.

ISO 9096:1992, *Stationary source emissions — Determination of concentration and mass flow rate of particulate material in gas-carrying ducts — Manual gravimetric method*.

3 Definitions and symbols

For the purposes of this International Standard, the definitions and symbols given in ISO 9096 apply. For the user's convenience, these symbols are defined in this International Standard at the point where they are first used.

4 Principle

The average velocity of the gas stream is determined using a Pitot tube to determine the velocity head, v , at selected points in the cross-section of the duct. The volume flowrate, q_v , is calculated by multiplying the cross-sectional area by the average velocity of the gas stream at that cross-section.

The method consists of:

- a) determining the dimensions, D , of the duct at the sampling location;
- b) determining the number, n , and location, x , of the measuring points in the cross-section needed to adequately determine the velocity profile;
- c) measuring the pressure differential, Δp , across the Pitot tube pressure ports when the Pitot tube is placed at these sampling points;
- d) determining the velocity at each sampling point from given formulae on the basis of these differential pressure measurements; and
- e) calculating the volume flowrate from the product of the average velocity and the cross-sectional area.

5 Apparatus

5.1 Design of the Pitot tube

The type L Pitot tube described in ISO 3966 is preferred when the velocity measurement is made before and after the pollutant sample is collected. This Pitot tube is less sensitive to flow misalignment errors than type S. However, its pressure-sensing ports can become plugged in certain sampling conditions. Its use could be difficult in high concentrations of particulate matter or aerosols. In addition, its insertion into thick-walled ducts or smokestacks requires large openings. If the type L Pitot tube and the sampling nozzle are too close to one another, they will adversely influence each other's performance.

The type S Pitot tube can be used when the pollutant sample is collected at the same time the velocity is measured. It is also preferred if the porthole is small, the stack wall is thick, the stack gas is dusty and the stack gas contains aerosols such as water droplets and H_2SO_4 . The type S Pitot tube is considerably more sensitive to alignment error than the type L Pitot tube, but it is less sensitive to interference by a sampling probe nozzle when the distance between the sides of the Pitot tube and the nozzle is at least 1,9 cm. The Pitot tube can be designed to reduce its sensitivity to alignment error.

5.1.1 Type L Pitot tube

This Pitot tube is sometimes termed the standard Pitot static tube or the Prandtl Pitot tube. Its design specifications are described in detail in annex A of ISO 3966:1977. Figure 1 shows an example of a type

L Pitot tube. Type L Pitot tubes meeting the design specifications in ISO 3966 also meet all the requirements of this International Standard. (Before it is used, however, the Pitot tube must be checked to ensure that it meets the design specifications of this International Standard.)

Type L Pitot tubes of other dimensions may also meet the requirements of this International Standard if they are calibrated against a standard Pitot static tube and used as described in this International Standard. The ISO 3966 type L Pitot tube consists of a cylindrical head attached perpendicularly to a stem. It has a calibration factor K of $0,99 \pm 0,01$.

At one or two cross-sections along the head, static-pressure holes are drilled around the circumference, so that the registered pressure is transferred through the head and stem to a point outside the duct.

A small tube, concentric with the head and stem, transfers the total pressure, registered by an orifice facing the flow direction (at the tip of an axially symmetrical nose integral with the head) to a point outside the duct. An alignment arm, fitted to the end of the stem, facilitates alignment of the head when this is obscured by the duct wall.

The nose (including the total pressure orifice) shall be designed to comply with the following requirements.

- a) The response of the differential pressure to inclination of the head relative to the flow shall meet one of the following two conditions (in both cases it is necessary to know the response curve of the Pitot tube):
 - 1) if precise alignment of the Pitot tube with the stack axis is not possible but there is no swirl, the differential pressure should be as independent as possible of the yaw of the head in uniform flow;
 - 2) if precise alignment of the Pitot tube with the conduit axis is possible but swirl is present, the variation of the differential pressure recorded by the tube in uniform flow with yaw angle ρ shall be approximately proportional to $\cos^2 \rho$. If the head is perfectly aligned axially and if swirl is less than $\pm 3^\circ$, the differential pressure shall not deviate from this requirement by more than 1 %.

NOTE 1 Misalignment and swirl can occur simultaneously and efforts should be made to minimize both.

- b) The calibration factors for different specimens of tubes to a particular specification shall be identi-

cal, to within $\pm 1,0 \%$, and shall remain so for the working life of any such tube. If the user has any doubt, an individual calibration of each Pitot tube should be made.

c) The static-pressure holes shall be:

- 1) not larger than 1,6 mm in diameter;
- 2) at least six, and sufficient in number for the damping in the static-pressure circuit to equal that in the total-pressure circuit; on Pitot tubes of small diameter, the orifices may be placed in two planes;
- 3) free of burrs and uniform in diameter;
- 4) placed not less than six head-diameters from the tip of the nose;

- 5) placed not less than eight head-diameters from the axis of the stem.

5.1.2 Type S Pitot tube

The type S Pitot tube is widely used in stack testing because it is suitable for determining the velocity at the point where the sample is being taken and because it is rugged, small and easy to construct. The construction specifications of this Pitot tube are shown in figure 2. This Pitot tube is normally made of metal tubing with an external diameter of 4 mm to 10 mm. The distance between the base of each leg of the Pitot tube and its face-opening (orifice) plane (dimensions L_1 and L_2 in figure 2) shall be equal for each leg. This distance shall be not less than 1,05 and not more than 10,0 times the external diameter of the tubing.

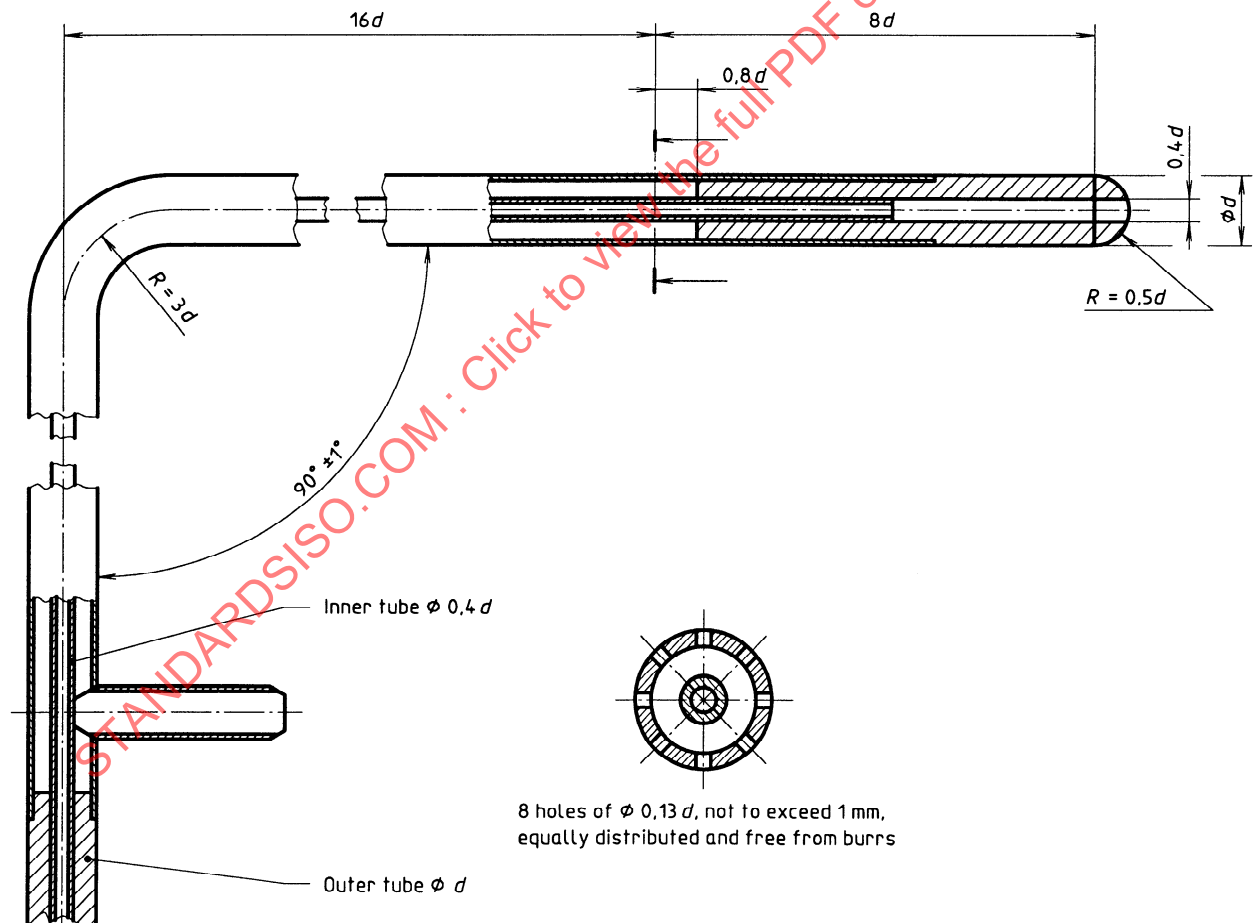


Figure 1 — Example of a type L Pitot tube

If this Pitot tube is to be used without a pollutant sampling probe attached to it, it should be calibrated with a type L Pitot tube to establish its calibration factor. However, if the specifications in figure 2 are met, a calibration factor K of $0,84 \pm 0,01$ may be assumed.

If it is used with a sampling probe attached, and the spacing between the Pitot tube, thermocouple and sampling nozzle conforms to that shown in figures 3 and 4, a calibration factor K of 0,84 may also be assumed. If these spacings are not met, the Pitot tube/sampling probe combination must be calibrated with a type L Pitot tube, as described in 5.2.

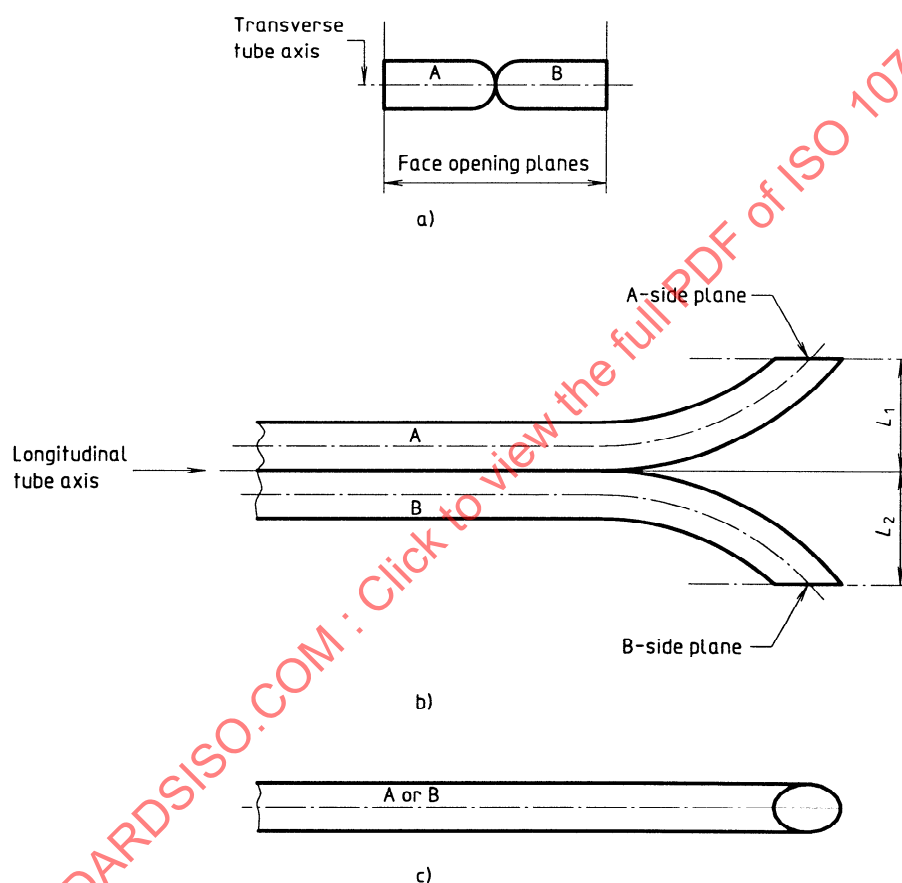
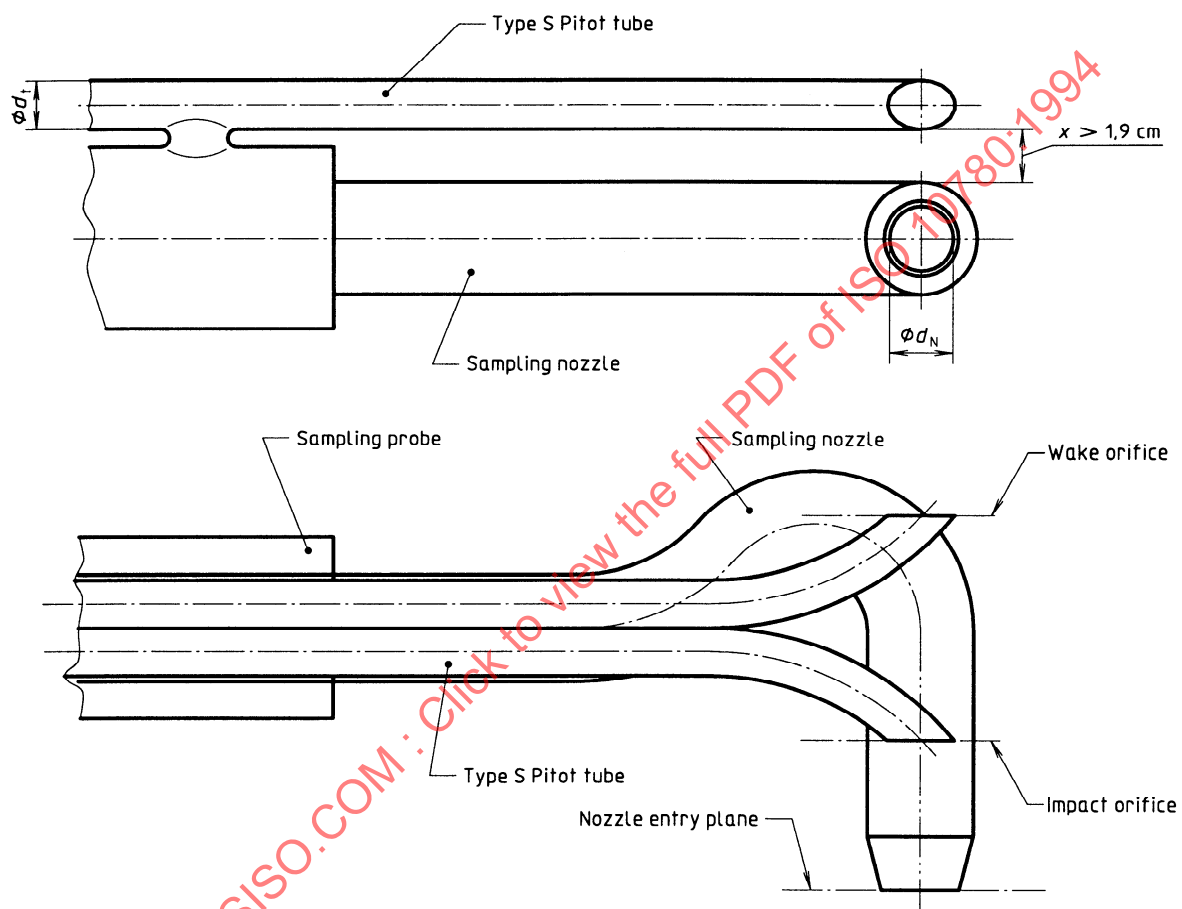


Figure 2 — Properly constructed type S Pitot tube



d_N = sampling nozzle diameter

d_t = type S Pitot tube diameter

Figure 3 — Type S Pitot tube: sampling nozzle spacing required to prevent flow measurement error when d_N equals 1,3 cm

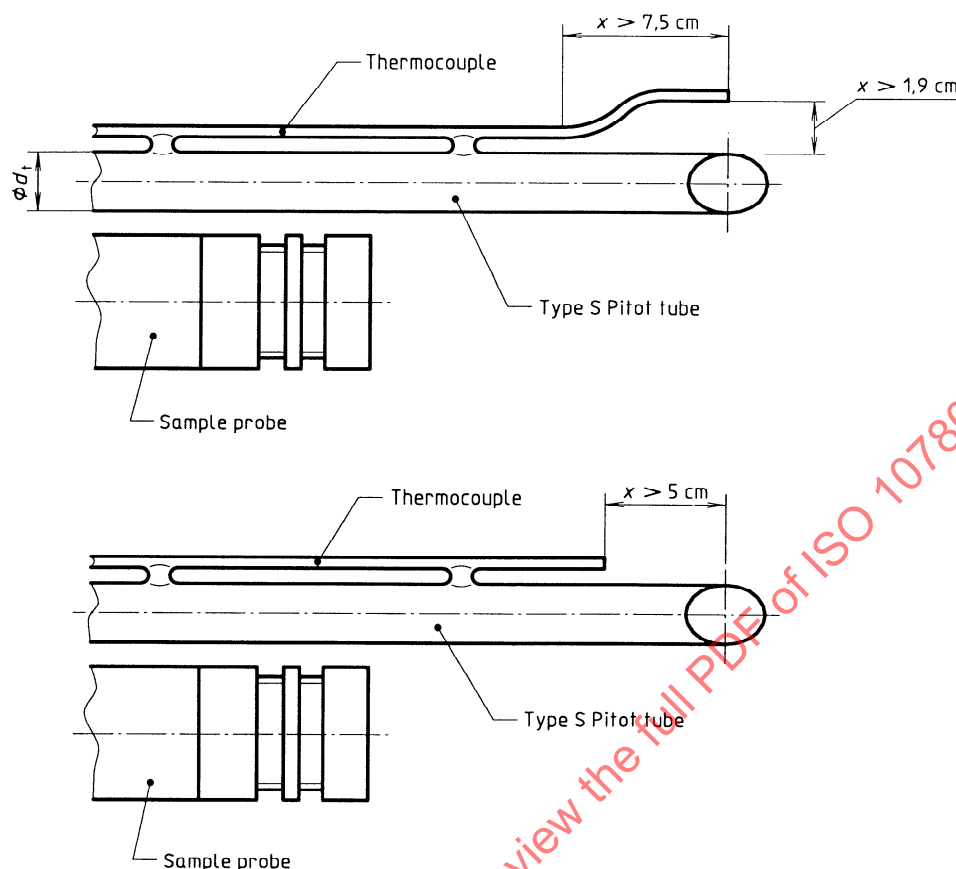


Figure 4 — Type S Pitot tube: thermocouple spacing required to prevent flow measurement error

5.2 Calibration of the Pitot tube

Type L Pitot tubes that do not meet the design specifications of this International Standard shall be calibrated with a Pitot tube which is in accordance with ISO 3966.

5.2.1 Characteristics of the calibration flow system

The flow system shall have the capacity to generate a velocity in the test section of between 11 m/s and 18 m/s. This velocity shall not vary by more than 1,0 % with time to ensure steady flow during the calibration of the Pitot tube. Pitot tubes and Pitot tube/sampling probe assemblies calibrated in this velocity range should be accurate within 3 % for velocities between 5 m/s and 50 m/s. If the Pitot tube or Pitot tube/sampling probe assembly is used to measure velocities below 5 m/s or above 50 m/s, the Pitot tube shall also be calibrated at these other velocities.

The projected area (blockage) of the Pitot tube or Pitot tube/sampling probe assembly shall not exceed 3 % of the cross-sectional area of the test section in the plane in which the calibration is being done.

5.2.2 Calibration procedure

A previously certified or calibrated type L Pitot tube shall be used as the reference standard. The Pitot tube shall be calibrated as follows.

- Ensure that the pressure-sensing device is properly zeroed, levelled, etc. and that the tubing connecting the Pitot tube to the pressure-sensing device is leaktight. Turn on the fan and allow the velocity in the test section to stabilize.
- Insert the type L Pitot tube into the test section, so that it is at least 8 cm from any interior wall.

Seal the porthole so that air does not leak out from the test section and measure the pressure difference (Δp_{ref}), in pascals (Pa) or equivalent units. Record this value (run 1) using the data form in figure 5 or its equivalent.

- c) Remove the type L Pitot tube and insert the Pitot tube to be calibrated into the test section at the same location as the reference Pitot tube. Seal the porthole as before and repeat the procedure in step b). Record the pressure difference (Δp_{unk} in figure 5 run 1).
- d) Repeat steps b) and c) until three pairs of Δp readings are obtained.

- e) Calculate K for each pair of Δp readings using equation (1) and determine the average K for the Pitot tube being calibrated. If any individual K differs from the average K by more than 0,02, the calibration must be repeated or the Pitot tube must be replaced.

$$K_{\text{unk}} = K_{\text{ref}} \sqrt{\frac{\Delta p_{\text{ref}}}{\Delta p_{\text{unk}}}} \quad \dots (1)$$

When calibrating a type S Pitot tube, compare the calibration factors determined with first one leg and then the other leg pointing downstream. Use this Pitot tube only if the two factors differ by no more than 0,01.

Date	
Pitot tube	
Calibrated by	
Type of Pitot tube	
Δp in units of	

	Run	Δp_{ref}	Δp_{unk}	K_{ref}	K_{unk}
Part A	1				
	2				
	3				
Part B ¹⁾	4				
	5				
	6				
NOTE — ref = reference; unk = unknown.					
1) Part B is used for type S Pitot tubes when both legs of the Pitot are calibrated.					

Figure 5 — Pitot tube calibration form

5.3 Ancillary equipment

Table 1 summarizes the requirements for ancillary equipment to be used with the Pitot tube.

6 Environmental requirements

The Pitot tubes described in this International Standard will provide the accuracy specified in clause 10 when the following conditions are met.

- a) The Reynolds number of the gas stream at the Pitot tube surface shall be greater than 1 200 and the gas stream velocity between 5 m/s and 50 m/s.

NOTE 2 Pitot tubes are subject to significant errors for Reynolds numbers less than 1 200. At velocities greater than 50 m/s, the Pitot tube tends to vibrate or undergo deflections that can cause significant errors in the pressure measurement.

- b) The swirl angle shall be not more than $\pm 15^\circ$ from the local direction of flow parallel to the duct axis at any point in the plane of measurement.

NOTE 3 A method to check for swirl using the Pitot tube is presented in annex C, and a method to straighten the flow is described in annex D.

- c) There shall be no regular or cyclic pressure fluctuations in the gas stream. Also, any irregular pressure fluctuations at the plane of measurement shall not exceed 24 Pa ($\pm 2,5 \text{ mmH}_2\text{O}$) about the mean value of the pressure difference reading on an undamped manometer connected to the Pitot tube by the shortest possible length of tubing. Small irregular fluctuations inevitably occur and will be reflected in the manometer reading. When testing is conducted to determine whether the observed fluctuations exceed 24 Pa about the mean reading, it should be established that the damping of the Pitot tube is symmetrical and equal for the Pitot orifices.

NOTE 4 A method for damping irregular pressure fluctuations is described in annex D of ISO 3966:1977.

Table 1 — Ancillary equipment and design specifications

Part	Design	Specification
Sensitive differential instrument connected to Pitot tube	Inclined liquid manometer or equivalent	Liquid manometer which can be read to within 0,13 mmH ₂ O
Instrument for measuring the humidity of gases in duct (optional)	Condenser, wet-and-dry-bulb thermometer, dryer	To measure water content of stack gas to within 2 % of gas volume
Thermometer for measuring duct temperature	Thermometer, shielded thermocouple or equivalent	Accurate to within 1 % of absolute temperature when immersed in a constant temperature bath
Porthole sealing device	Foam, adjustable flange or equivalent	Of sufficient size to seal porthole during velocity measurement
Barometer for measuring local atmospheric pressure	Pressure gauge	Accurate to within 300 Pa
Device for measuring duct dimensions	Calibrated rod (preferred) or reliable drawings when duct is too large to measure with a calibrated rod	Internal dimensions of duct or chimney shall be measured to within 1 % of linear dimension
Instrument for measuring static pressure in duct	Pitot tube attached to manometer	Accurate to within 0,2 % absolute pressure in duct (see annex B)
Instrument for measuring gas composition (optional)	Orsat analyser or other device as appropriate	Gas density accurate to within 2 %

- d) For circular stacks, measurements shall be made over at least two diameters that are at right angles to each other, and the difference between the average velocities across each diameter should not exceed 5 % of the mean for all the diameters. If the difference exceeds 5 %, additional sampling points shall be taken or a new sampling location selected.
- e) The internal dimensions of the duct shall be known to within 1 % of the duct linear dimensions.
- f) The duct shall not exhibit any sudden variations in its internal diameter for a distance of at least 5 hydraulic diameters upstream and 5 hydraulic diameters downstream from the plane in which the velocity will be measured.

NOTE 5 For noncircular ducts, the hydraulic diameter is calculated by multiplying the duct cross-sectional area by four and dividing the resulting quantity by the duct perimeter.

- g) A negative flow stream shall not be present at any point on the cross-sectional area where the Pitot tube will be used.
- h) The absolute temperature at each velocity measurement point shall not differ by more than 5 % from the average absolute temperature of the duct cross-section.

NOTE 6 Temperature differences greater than 5 % indicate that stratified flow is present at the sampling location.

7 Test procedure

7.1 Before testing

7.1.1 Site survey

Before carrying out any measurements, discuss the purpose of the sampling with the management of the plant. The nature of the plant process, for example steady-state or cyclic, can affect the sampling program. If the process can be performed in a steady state, it must be conducted under steady operating conditions that are as ideal as possible during the sampling.

A preliminary survey of the plant will facilitate the selection of the best sampling location and the determination of the required number and pattern of the sampling points.

From the information collected, select the proper Pitot tube and plan the test procedures. Discuss with the management of the plant which provisions are available or still have to be provided. Dates, starting times, duration of the survey and sampling periods, as well as plant operating conditions during these periods, shall be agreed with the management of the plant.

7.1.2 Choice of sampling location

Sampling shall take place in a length of straight duct with constant shape and cross-sectional area, and as far as possible downstream from any obstruction which may cause a disturbance and produce a change in the direction of flow. The cross-sectional area must be sufficiently large to avoid increasing the duct gas stream velocity by more than 3 % due to blocking caused by the Pitot tube and any probes or thermocouples attached to it.

To ensure a sufficiently homogeneous gas velocity distribution in the sampling plane, this section of straight duct should be at least 7 hydraulic diameters long. Over the length of the straight section, locate the sampling plane at a distance of 5 hydraulic diameters from the inlet. If the sampling plane is to be located in a duct near the gas stream exit to the atmosphere, the distance to the duct exit should also be 5 hydraulic diameters (making a straight length of 10 hydraulic diameters). The gas flow conditions shall meet the criteria described in clause 6. This must be verified prior to sampling. If these specifications for hydraulic diameter are not met, it cannot be assumed that the accuracy specified in clause 10 will be obtained.

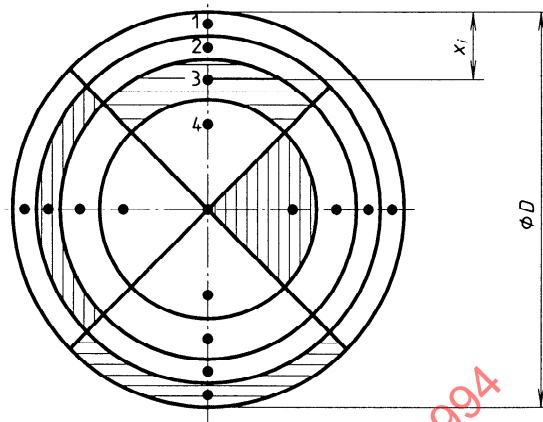
If sampling in horizontal ducts is unavoidable, practical advantages may be taken of access ports situated on the top of the duct. However, the Pitot tube orifices shall not contact any deposits in the bottom of the duct.

7.1.3 Number of sampling points

The minimum number of sampling points is dictated by the dimensions of the measuring plane. In general, this number increases as stack cross-section increases. The minimum number of sampling points required is given in tables 2 and 3 for circular and rectangular ducts, respectively.

7.1.4 Location of sampling points

The sampling plane shall be divided into equal areas and a velocity measurement taken at the centre of each area. However, no sampling point shall be located within 2 cm of the duct wall. If this latter situation arises, the sampling point shall be adjusted so that the Pitot tube is positioned 2 cm from the wall.



NOTE — The shaded portions are of equal area; $D > 2$ m.

7.1.4.1 Circular duct, general rule

The duct is divided into equal areas as shown in figure 6. Sampling points are selected using table 4.

Figure 6 — Sampling point positions in circular ducts — General rule

Table 2 — Minimum number of sampling points for circular ducts having cross-sectional areas $\geq 0,07$ m²

Sampling plane area m ²	Duct diameter m	Minimum number of sampling lines (diameters)	Minimum number of sampling points per diameter		Minimum number of sampling points per plane	
			Centre point incl.	Centre point excl.	Centre point incl.	Centre point excl.
0,07 to 0,38	0,3 to 0,7	2	3	2	5	4
0,38 to 0,79	0,7 to 1	2	5	4	9	8
0,79 to 3,14	1 to 2	2	7	6	13	12
> 3,14	> 2	2	9	8	17	16

Table 3 — Minimum number of sampling points for rectangular ducts having cross-sectional areas $\geq 0,07$ m²

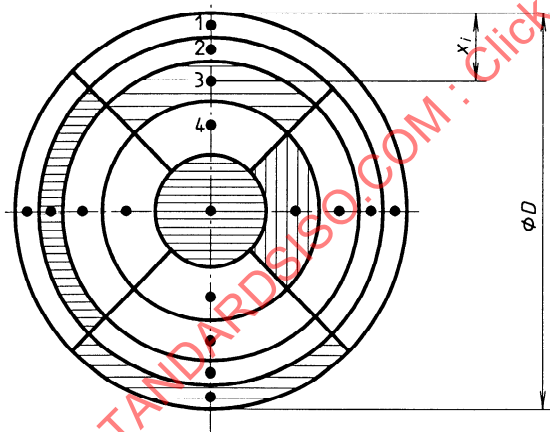
Sampling plane area m ²	Minimum number of side divisions	Minimum number of sampling points
0,07 to 0,38	2	4
0,38 to 1,5	3	9
> 1,5	4	16

Table 4 — Sampling point (as a percentage of the diameter D) distance from the duct wall, general rule (see figure 6)

Sampling point number i	%D			
	Number of sampling points, n_d , on a diameter			
	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

7.1.4.2 Circular duct, tangential rule

The duct is divided into equal areas, but there is no sampling point at the centre of the duct (figure 7). Sampling points are selected using table 5.



NOTE — The shaded portions are of equal area; $D > 2$ m.

Figure 7 — Sampling point positions in circular ducts — Tangential rule

Table 5 — Sampling point (as a percentage of the diameter D) distance from the duct wall, tangential rule (see figure 7)

Sampling point number i	%D			
	Number of sampling points, n_d , on a diameter			
	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

7.1.4.3 Rectangular duct

The duct is divided into equal areas at the sampling point by lines parallel to the sides of the ducts, and the sampling points are located at the centre of each area (see figure 8).

7.1.4.4 Special instructions

When using this International Standard, several additional points should be considered. Firstly, the minimum number of sampling points required for measuring velocity and volumetric flow usually will also be adequate for determining gaseous pollutant emissions, but may not be adequate for measuring particulate and aerosol emissions. Secondly, a location that is adequate for measuring flow may not meet the minimum requirements for collecting a pollutant sample. When a pollutant sample is also to be taken, the pollutant sampling method should be consulted to determine if the requirements for sampling point selection in this International Standard also meet the requirements of the pollutant sampling method. When there is a difference, the most rigorous sampling point selection of the two standards shall be used.

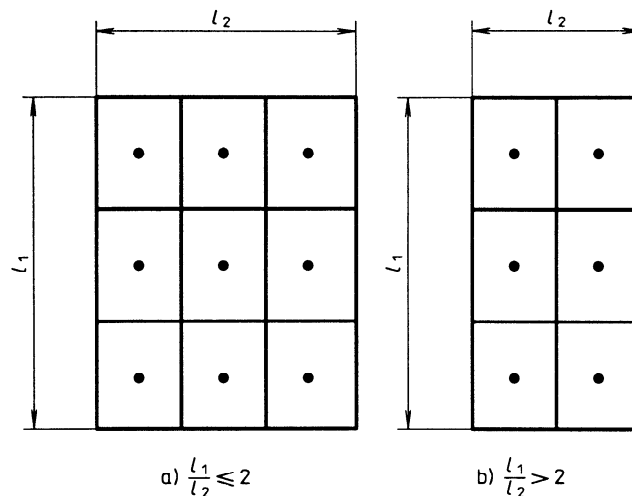


Figure 8 — Sampling point positions in rectangular (and square) ducts

7.1.5 Size and position of access ports

Ports shall allow access to the sampling points selected in accordance with 7.1.4. Port dimensions depend on the dimensions of the related sampling equipment but should offer ample space for inserting or removing this equipment.

7.1.6 Working platform

The platform, permanent or temporary, shall have an adequate working area and shall be provided with handrails positioned at a height of 1 m above the platform surface. 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 these are to be exposed to moisture or condensation.

7.1.7 Choice of apparatus

The apparatus used depends upon the local circumstances at the plant, the experience of the tester and the equipment available. Take into account the following factors:

- a) the likely concentration of solids and aerosols;
- 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 chemical composition of the flue gases in relation to the materials from which the apparatus is constructed;

- e) the highest temperature that the measurement apparatus can safely withstand;
- f) the internal dimensions of the duct in relation to the dimensions of any part of the equipment that will be within the duct; the projected area of that part shall not exceed 5 % of the sampling plane area;
- g) the velocity range of the duct gases;
- h) the static pressure in the duct;
- i) the likely hazards to operators.

7.1.8 Preparation of apparatus

Before moving it to the sampling platform, prepare the equipment in a clean working environment, either on-site or before arriving at the site. Check all pressure- and temperature-measuring instruments, rubber or plastic tubing or any other accessories to ensure that they are in good condition. Check the Pitot tube to ensure that the orifices are clear of dirt, burrs, etc. and to ensure that the pressure-sensing orifices are properly aligned. Calibrate all parts of the equipment that need calibration. Check the assembly for the absence of leaks using the procedures in annex A or an equivalent procedure.

7.2 Testing

Move the equipment to the sampling platform. Measure the internal dimensions of the stack to within 1 % of the linear dimension by using the stack dimension measuring device described in table 1 (preferred) or reliable engineering drawings. Determine

the number of sampling points in accordance with 7.1.3 and determine the location of the sampling points with respect to the duct walls in accordance with 7.1.4. Now mark the positions of the sampling points on the Pitot tube or Pitot tube/sampling probe assembly, using heat-resistant tape and a marking pen, or some equivalent method.

After making sure that the plant is operating at the desired process conditions, connect the two legs of the Pitot tube to the Δp measuring device. Inspect the Pitot tube to be sure that the orifices are clear of obstructions. Again check the assembly for the absence of leaks and verify that the pressure-sensing orifices are properly aligned. Unless there are previous data that show swirling flow is not present, insert the Pitot tube to check for the presence of swirling flow by using one of the techniques in annex C. Carry out this check at all sampling points on each traverse diameter. If the gas stream flow is shown to be aligned within 15° of the duct main axis at all sampling points, proceed as follows.

- Determine and record the duct static pressure at one point on each traverse diameter using one of the techniques described in annex B.
- Align the Pitot tube with the duct axis at each sampling point, and measure and record the differential pressure (Δp).

NOTE 7 If the duct contains high concentrations of particles or droplets, the Pitot tube should be back-purged with air during the traverse to ensure that the orifices remain open.

- Measure and record the ambient pressure (p_{am}), in kilopascals, at the sampling site.
- Measure and record the duct temperature, in kelvins.

Figure 9 shows a sample form for recording the above data.

8 Calculation of velocity and volume flowrate

8.1 General

To measure the velocity and volume flowrate with the highest accuracy, it is necessary to know the molecular composition, the density and the moisture content of the stack gas. Methods to determine the molecular composition of the stack gas are readily available, as are methods for measuring the moisture content [for example, silica gel, a psychrometer

(wet-and-dry-bulb thermometer), a condenser or a set of ice-cooled impingers]. The results of these measurements can then be used to determine the stack gas density in accordance with ISO 9096. However, in most cases the density of the stack gas, even from combustion processes, closely approximates the density of air. (For combustion process streams, carbon dioxide and water vapour cause deviations that are small and of opposite signs.)

It is assumed in this International Standard that the density of the stack gas at stack temperature is approximately the same as that of air. If this condition is not met, then the equations in ISO 9096:1992, 13.2 shall be used.

8.2 Gas velocity

8.2.1 Average static pressure, $\bar{p}_{\text{static}}$

Determine the arithmetic average for all static pressure readings at the sampling points and convert this value to kilopascals.

8.2.2 Absolute gas pressure, p_e

Add the average value from 8.2.1 to the ambient (barometric) pressure (p_{am}) to obtain the absolute gas pressure in the duct (p_e). This may be less or greater than p_{am} .

8.2.3 Average Pitot tube pressure difference $\Delta\bar{p}$

Determine the average Pitot tube pressure difference $\Delta\bar{p}$ using equation (2):

$$\Delta\bar{p} = \frac{1}{n^2} \left(\sum_{i=1}^n \sqrt{\Delta p_i} \right)^2 \quad \dots (2)$$

where Δp_i is the individual velocity head (pressure difference) at point i .

Convert this value to kilopascals.

8.2.4 Average gas velocity, $\bar{v}$

Determine the average gas velocity in the sampling plane using equation (3):

$$\bar{v} = KC \sqrt{\frac{T_s \Delta\bar{p}}{p_e M_s}} \quad \dots (3)$$

where

C is equal to $129 \text{ (m/s)} \cdot [\text{kg}/(\text{kmol} \cdot \text{K})]^{1/2}$;

T_s is the average stack gas temperature, in kelvins;

M_s is the molar mass of gas; assume a value of 29 kg/kmol unless the molar mass is less than 27 kg/kmol or greater than 31 kg/kmol;

K is the Pitot tube coefficient;

p_e is the absolute gas pressure, in kilopascals;

$\Delta \bar{p}$ is the average Pitot tube pressure difference, in kilopascals.

Plant name				
Date of test			Run No.	
Duct diameter (m) or dimensions (m ²)				
Ambient pressure (kPa)				
Cross-sectional area of duct (m ²)				
Pitot tube: internal diameter			K	
Date of calibration of Pitot tube				
Traverse point No.	Δp Pa	Duct temperature K	Duct static pressure Pa	

Figure 9 — Example of a velocity traverse data sheet

8.3 Volume flowrate q_{Vs}

The volume flowrate at stack conditions q_{Vs} can be calculated using equation (4):

$$q_{Vs} = \bar{v}A \quad \dots (4)$$

where

- $\bar{v}$ is the velocity, in metres per second, at stack conditions;
- A is the cross-sectional area of the stack, in square metres, at the sampling point;
- q_{Vs} is the volume flowrate, in cubic metres per second.

Equation (5) can be used to correct q_{Vs} on a wet basis to the standard reference conditions q_{Vs} of 0 °C and 101,3 kPa;

$$q_{Vr} = q_{Vs} \left(\frac{273}{T_s} \right) \left(\frac{P_e}{101,3} \right) \quad \dots (5)$$

9 Accuracy

Under the conditions specified in clause 6 of this International Standard, the total error associated with the velocity measurement for the duct is less than 3 % and for any one point should be less than 5 %. The presence of aerosols and particles, which may plug the Pitot orifices, may increase the error.

Increasing the number of sampling points can improve the accuracy somewhat, but after a total of 16 points is reached the improvement is very small. A more accurate determination of the molecular composition, density and moisture content of the gas stream also increases the accuracy, but the improvement is likely to be less than 5 %.

10 Test report

The test report should include at least the following items:

- a) date, time and place of the measurement;
- b) conditions of the measurement, as appropriate:
 - character of the source tested;
 - conditions of the source during the testing period (plant load, throughput);
 - sampling location;
 - shape and size of the duct;
 - number of sampling points;
- c) conditions of the gas in the duct:
 - static pressure;
 - temperature;
 - water content;
 - composition;
 - presence of particles and aerosols;
 - velocity;
 - volume flowrate;
- d) reference to this International Standard, including any procedural or equipment requirements that could not be met, and how this was compensated for.