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Permeable sintered metal materials — Determination of fluid permeability

Matériaux métalliques frittés perméables — Détermination de la perméabilité aux fluides

Reference number
ISO 4022 : 1987 (E)

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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 4022 was prepared by Technical Committee ISO/TC 119, *Powder metallurgy.*

This second edition cancels and replaces the first edition (ISO 4022 : 1977), of which it constitutes a minor revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Permeable sintered metal materials — Determination of fluid permeability

1 Scope and field of application

This International Standard specifies a method for the determination of the fluid permeability of permeable sintered metal materials in which the porosity is deliberately continuous or interconnecting, testing being carried out under such conditions that the fluid permeability can be expressed in terms of viscous and inertia permeability coefficients (see annex A).

This International Standard does not apply to very long hollow cylindrical test pieces of small diameter, in which the pressure drop of the fluid in passing along the bore of the cylinder may not be negligible compared with the pressure drop of the fluid passing through the wall thickness (see annex A, clause A.5).

2 Reference

ISO 2738, *Permeable sintered metal materials — Determination of density, oil content and open porosity.*

3 Principle

Passage of a test fluid of known viscosity and density through a test piece, and measurement of the pressure drop and the volumetric flow rate.

Determination of the viscous and inertia permeability coefficients, which are parameters of a formula describing the relationship between the pressure drop, the volumetric flow rate, the viscosity and density of the test fluid, and the dimensions of the porous metal test piece permeated by this fluid.

4 Symbols and definitions

For the purposes of this International Standard, the symbols and definitions given in the table apply:

Table — Symbols and definitions

Term	Symbol	Definition	Unit
Permeability	—	Ability of a porous metal to pass a fluid under the action of a pressure gradient	—
Test area	A	Area of a porous metal normal to the direction of the fluid flow	m^2
Thickness	e	Dimension of the test piece in the direction of fluid flow a) for flat test pieces: equal to the thickness b) for hollow cylinders: given by the equation in 6.1.2	m
Length	L	Length of cylinder (see figure 2)	m
Viscous permeability coefficient	ψ_v	Volume flow rate at which a fluid of unit viscosity is transmitted through unit area of porous metal permeated under the action of unit pressure gradient when the resistance to fluid flow is due only to viscous losses. It is independent of the quantity of porous metal considered.	m^2
Inertia permeability coefficient	ψ_i	Volume flow rate at which a fluid of unit density is transmitted through unit area of porous metal permeated under the action of unit pressure gradient when the resistance to fluid flow is due only to inertia losses. It is independent of the quantity of porous metal considered.	m
Volume flow rate	Q	Mass flow rate of the fluid divided by its density	m^3/s
Upstream pressure Downstream pressure Mean pressure	p_1 p_2 p	Pressure upstrean of the test piece Pressure downstream of the test piece Half the sum of the upstream and downstream pressures	N/m^2
Pressure drop	Δp	Difference between the pressures on the upstream and downstream surfaces of the porous test piece	N/m^2
Pressure gradient	$\Delta p/e$	Pressure drop divided by the thickness of porous test piece	N/m^3
Velocity	Q/A	Ratio of the volumetric flow rate to the test area	m/s
Density	ϱ	Density of the test fluid at the mean temperature and pressure	kg/m^3
Dynamic viscosity	η	Absolute dynamic viscosity coefficient as defined by Newton's law	$N \cdot s/m^2$
Apparatus correction (to be subtracted from the observed pressure drop)	—	Pressure difference observed between the upstream and downstream pressure tappings when the test apparatus is used without a porous test piece in position. (It varies with the flow rate through the apparatus and arises from venturi effects at the pressure tappings and other causes)	N/m^2
Mean absolute temperature	T	Half the sum of the temperatures of the fluid at the upstream side and the downstream side of the test piece	K

5 Test piece

Before testing with gas, all liquid shall be removed from the pores of the test piece. Oil and grease shall be removed by using a suitable solvent with the extraction method given in ISO 2738. The test piece shall be dried before testing.

6 Apparatus

6.1 Equipment

The choice of apparatus is mainly dictated by the size, shape and physical characteristics of the test piece.

This International Standard refers to two different types of apparatus suitable for determining the fluid permeability of porous test pieces.

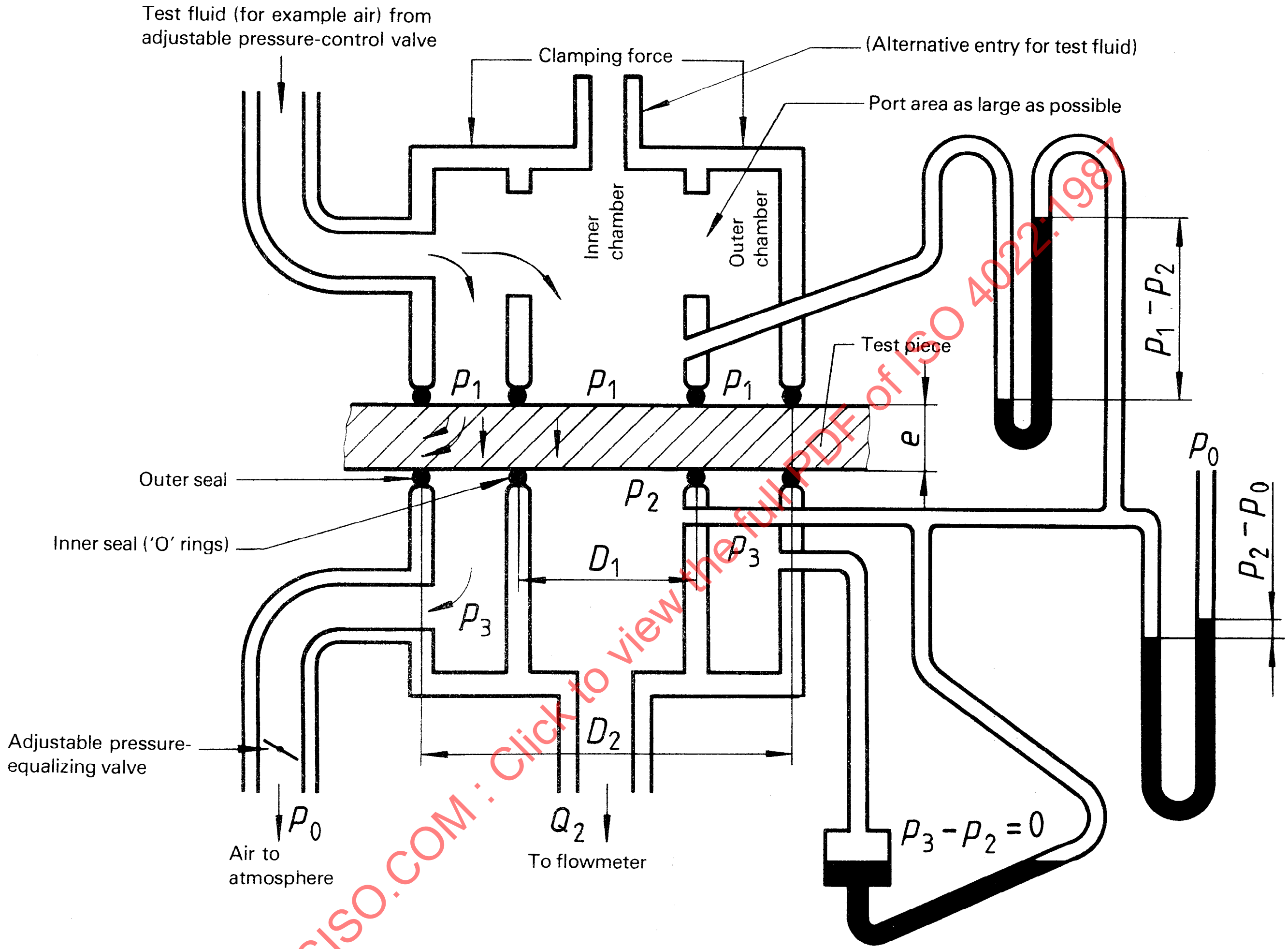
6.1.1 Guard ring test head for flat test pieces

This is a type of test apparatus which is recommended for carrying out non-destructive testing of partial areas of flat porous sheets.

The permeable metal sheet is clamped between two pairs of flexible seals. The inner pair, corresponding to the test area, has a mean diameter of D_1. The outer pair, of mean diameter D_2, forms a guard ring surrounding the test-area, which is pressurized to prevent side leakage from the test area (see figure 1). The width of the annulus formed by the guard ring test head shall be not less than the thickness of the sheet, i.e.:

$$\frac{D_2 - D_1}{2} \geqslant e$$

The guard ring test head minimizes side leakage by ensuring that the pressure is the same in the inner and outer chambers. On the upperstream face of the test piece, this is achieved by arranging that the port area connecting the upper chambers (as shown in figure 1) is as large as possible. On the downstream face of the test piece, the inner chamber leads to a flowmeter, usually subject to a small back pressure, and the outer chamber



D_1 = Mean diameter of the inner seals
D_2 = Test head diameter
Q_2 = Volumetric flow rate, at pressure p_2
p_0 = Atmospheric pressure
p_3 = Downstream guard ring pressure, adjusted to be equal to p_2
$p_2 - p_0$ = Pressure drop across flowmeter
$p_1 - p_2$ = Pressure drop across porous metal

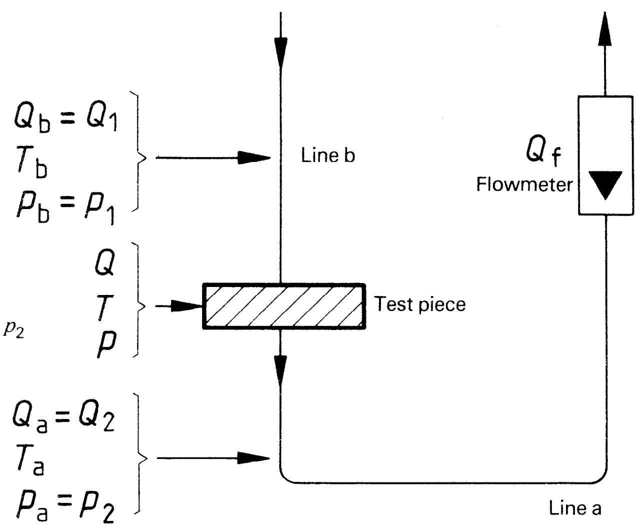


Figure 1 — Guard ring test head

leads to atmosphere via a pressure-equalizing valve. This valve is adjusted to equalize the pressure in the inner and outer chambers. The fitting of a restrictor between the test piece and the flowmeter, to increase the back pressure and thus permit more stable control of the pressure-equalizing valve, is allowed.

However, ideally, the pressure on the downstream face of the test piece should be as near as possible to atmospheric pressure and a restrictor should not be used unless necessary for the adjustment of the pressure drop in the flowmeter.

Toroidal sealing rings ("O"-rings) are recommended for the inner seals.

The seals shall be sufficiently flexible to overcome all surface imperfections and lack of flatness of the porous metal. In some instances it may be necessary to load the inner and outer seals separately to ensure leak-free sealing.

Two upper and two lower seals are required and these shall be in line with each other.

6.1.2 Jig for hollow cylindrical test pieces

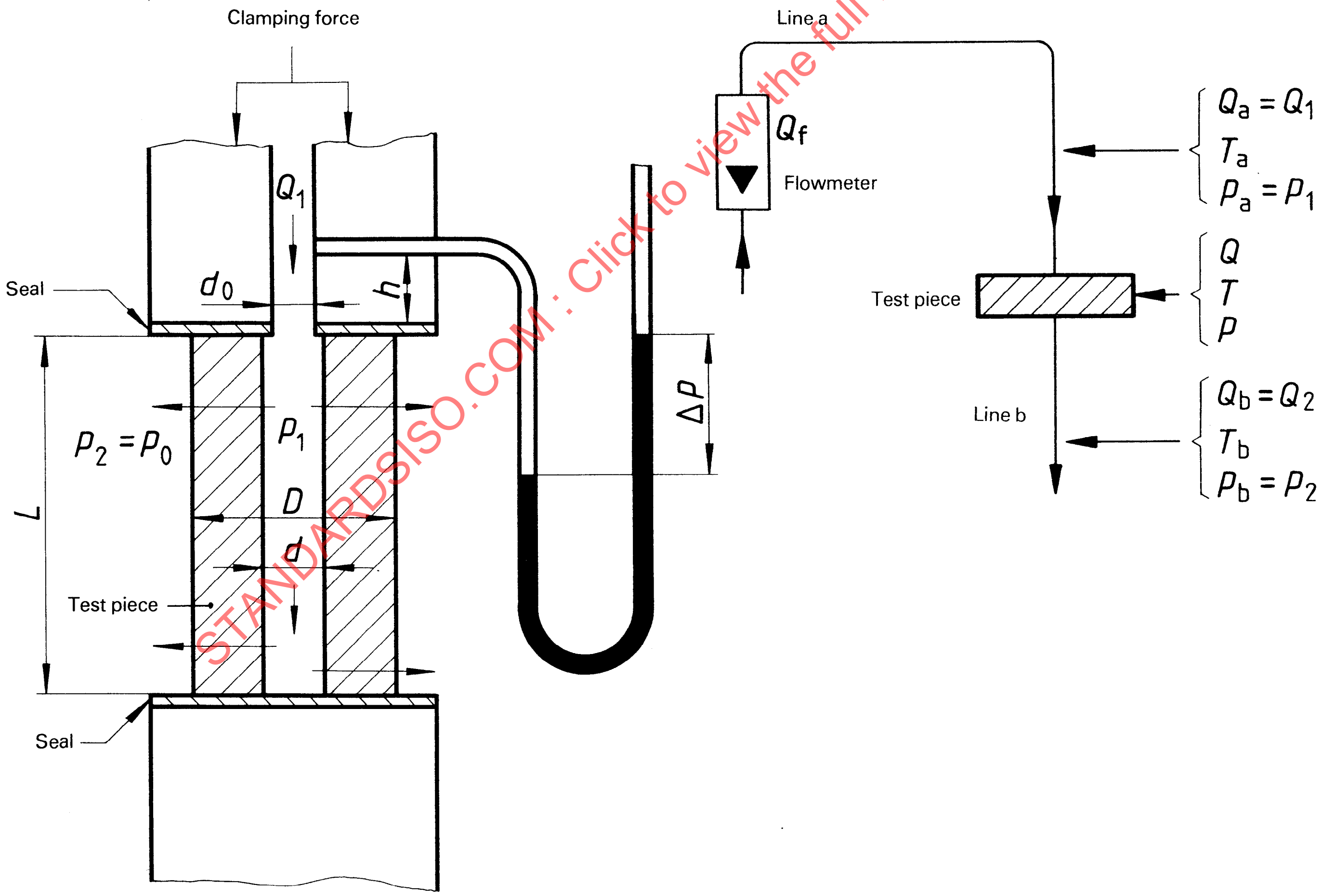
The permeability of hollow cylindrical test pieces is conveniently measured by clamping the cylinder axially between two flat surfaces and causing the test fluid to permeate outwards through the wall of the cylinder. An example is shown in figure 2. The flowmeter is placed upstream of the test piece. When clamping the porous metal cylinder under test, sufficiently flexible seals shall be used to overcome surface irregularities so as to ensure leak-free sealing.

6.2 Test fluids

In the majority of cases, gases are more convenient test fluids than liquids (see annex B).

Test gases shall be clean and dry.

By agreement between the interested parties, liquids may be used where the permeability with reference to a specific liquid is required. This liquid shall be clean and free from dissolved gases.



NOTE — The diameter d_0 should be approximately equal to diameter d and the distance h should be as small as possible to minimize the apparatus correction.

Figure 2 — Jig for testing hollow cylindrical test pieces

7 Procedure

7.1 Measurement of thickness and area of the test piece

7.1.1 Flat test pieces

The size of micrometer anvils shall not be larger than the size of the surface irregularities, nor smaller than the pore size.

The test area is defined as that area normal to the direction of fluid flow, and, provided that the pressure gradient is uniform, this definition is meaningful and the test area is readily measured.

7.1.2 Hollow cylindrical test pieces

For hollow cylinders, the thickness e and the test area A are given by the following relationships:

$$\frac{D_2 - D_1}{2} \geqslant e$$

$$e = \frac{D \times (\ln r)^2}{2\,(r - 1)}$$

$$A = \frac{\pi \times D \times L \times \ln r}{r - 1}$$

where $r = \dfrac{D}{d}$ (see figure 2)

When the wall thickness $\dfrac{D - d}{2}$ is small compared with d, for example less than 0,1 d, the thickness e and test area A are given by the following equations:

$$e = \frac{D - d}{2}$$

$$A = \frac{\pi \times L \times (D + d)}{2}$$

7.2 Measurement of pressure drop

The pressure drop may be determined either by measuring the upstream and downstream pressures separately and taking the difference or by using a differential pressure gauge.

The apparatus correction is obtained by using the equipment with no test piece in place and observing the pressure drop over the required range of flow rates. The apparatus correction should preferably not exceed 10 % of the pressure drop (see the table).

7.3 Measurement of flow rate

A primary standard for the measurement of the flow rate of the test fluid is preferred. The flow rate shall be corrected to the mean pressure and temperature of the test piece. However, a standard flowmeter (previously calibrated against a primary standard) may be more convenient to use.

7.4 Measurement of pressures and temperatures

It is necessary to measure the pressure and temperature at the flowmeter and the test piece in order to

- correct the reading of the flowmeter;
- calculate the mean flow rate through the test piece;
- determine the density and the viscosity of the test fluid.

8 Expression of results

8.1 Mean flow rate

The reading of the flowmeter Q_f is corrected if it is not being used at its calibration pressure and temperature, by using the flowmeter correction factor C_f given by the manufacturer. The corrected flowmeter reading Q_a is given by the following equation:

$$Q_a = C_f \times Q_f$$

The corrected flowmeter reading Q_a is converted to the mean flow rate Q within the porous test piece using the correction term C_s, which can be calculated from the gas law equation:

$$C_s = \frac{Q}{Q_a} = \frac{p_a}{p} \times \frac{T}{T_a}$$

The mean flow rate is $Q = C_s \times Q_a$.

When tabulating data, it is convenient to use the overall correction factor C_o:

$$C_o = C_f \times C_s$$

to obtain the mean flow rate $Q = C_o \times Q_f$.

8.2 Mean density and viscosity

The mean pressure and the mean absolute temperature within the test piece will enable mean density and mean viscosity to be obtained from published data.

8.3 Calculation of results

The viscous and inertia permeability coefficients are determined by taking a number of simultaneous flow rate and pressure drop readings. The number of flow rate readings shall be at least five, equally spaced within an interval of flow rate readings where the highest is at least ten times greater than the lowest.

The results are processed using the following equation:

$$\frac{\Delta p \times A}{e \times Q \times \eta} = \frac{1}{\psi_i} \times \frac{Q \times p}{A \times \eta} + \frac{1}{\psi_v}$$

[see annex A, equation (2)].

This equation can be re-written in the form $y = ax + b$ where

$$y = \frac{\Delta p \times A}{e \times Q \times \eta}$$

$$x = \frac{Q \times \varrho}{A \times \eta}$$

The values x and y are calculated at each level of flow rate/pressure drop. The corresponding values of x and y are plotted on linear graph paper and the straight line which best fits the points is drawn.

The intercept of this line on the y-axis gives the reciprocal of the viscous permeability $(1/\psi_v)$.

The slope of this line gives the reciprocal of the inertia permeability $(1/\psi_i)$.

In case of doubt, the straight line should be determined by the least-squares method.

NOTE — If measurement is made with flow in the laminar regime, only the viscous permeability coefficient can be determined (see annex A).

8.4 Final result

Report of the viscous permeability coefficient in 10^{-12} m^2 (1 μm^2) and the inertia permeability coefficient in 10^{-6} m (1 μm). to an accuracy of ± 5 % in relative value.

NOTE — The unit of viscous permeability coefficient (micrometre squared) is sometimes called a darcy.

9 Test report

The test report shall include the following information:

a) reference to this International Standard;

b) all details necessary for identification of the test sample;

c) the type of apparatus used;

d) the test fluid used;

e) the result obtained;

f) all operations not specified by this International Standard or regarded as optional;

g) details of any occurrence which may have affected the result.

Annex A

The flow of fluid through porous materials

(This annex does not form an integral part of the Standard.)

A.1 Viscous flow

The empirical formula for the flow of fluids through porous materials was first given by Darcy, following experiments with water, and expresses the proportionality between the pressure drop per unit thickness and the flow rate per unit area and the viscosity. It can be written

$$\frac{\Delta p}{e} = \frac{Q \times \eta}{A \times \psi_v} \qquad \ldots (1)$$

and assumes that the losses are all due to viscous shear.

A.2 Viscous and inertia flow

In reality, the flow of fluid through porous materials can involve several mechanisms, many of which can be operating simultaneously. However, experience shows that in the majority of cases involving the flow of fluids through porous metals only three mechanisms are usually involved. They are: viscous flow, inertia flow and slip flow. Inertia flow concerns the loss of energy due to the changes in the direction of the fluid in passing through tortuous porosity and to the onset of local turbulences in the pores, and has been combined with the viscous loss equation of Darcy by Forchheimer to give the equation (slip flow usually absent)

$$\frac{\Delta p}{e} = \frac{Q \times \eta}{A \times \psi_v} + \frac{Q^2 \times \varrho}{A^2 \times \psi_i} \qquad \ldots (2)$$

which is used in 8.3 of this International Standard. However, at low velocities of flow (Q/A) of viscous fluids, the inertia term of equation (2) is usually insignificant compared with the viscous term and can be ignored to give the simpler equation (1).

A.3 Slip flow

Equation (1) assumes that the pore size is large compared with the mean free path of the molecules of the test fluid. This assumption is most likely to be invalid with a very small pore size and with gases at reduced pressure or high temperature. When the mean free path of the gas molecules approaches the same order of size as the pores of the metal, slip flow occurs. When slip flow is present, the porous metal appears to be more permeable than when slip flow is absent. Also, when slip flow is present, inertia losses are usually absent, so that equation (2) may be written in the form

$$\psi_s = \frac{Q \times \eta \times e}{A \times \Delta p} \qquad \ldots (3)$$

where ψ_s is the permeability coefficient with slip flow present.

The correction for slip flow is given by

$$\psi_s = \psi_v \times \left(1 + \frac{2 \times B}{p_1 + p_2}\right) \qquad \ldots (4)$$

where

ψ_s is the observed viscous permeability with slip flow present;

ψ_v is the true viscous permeability coefficient;

B is the Klinkenberg factor, which is a constant for a given gas and porous material, and has the dimensions of a pressure.