

# INTERNATIONAL STANDARD

ISO  
4022

Second edition  
1987-10-01



INTERNATIONAL ORGANIZATION FOR STANDARDIZATION  
ORGANISATION INTERNATIONALE DE NORMALISATION  
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

## **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 <sup>2</sup>
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	$\psi_v$	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 <sup>2</sup>
Inertia permeability coefficient	$\psi_i$	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 <sup>3</sup> /s
Upstream pressure	$p_1$	Pressure upstream of the test piece	N/m <sup>2</sup>
Downstream pressure	$p_2$	Pressure downstream of the test piece	
Mean pressure	$p$	Half the sum of the upstream and downstream pressures	
Pressure drop	$\Delta p$	Difference between the pressures on the upstream and downstream surfaces of the porous test piece	N/m <sup>2</sup>
Pressure gradient	$\Delta p/e$	Pressure drop divided by the thickness of porous test piece	N/m <sup>3</sup>
Velocity	$Q/A$	Ratio of the volumetric flow rate to the test area	m/s
Density	$\rho$	Density of the test fluid at the mean temperature and pressure	kg/m <sup>3</sup>
Dynamic viscosity	$\eta$	Absolute dynamic viscosity coefficient as defined by Newton's law	N·s/m <sup>2</sup>
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 <sup>2</sup>
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



## ISO 4022 : 1987 (E)

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

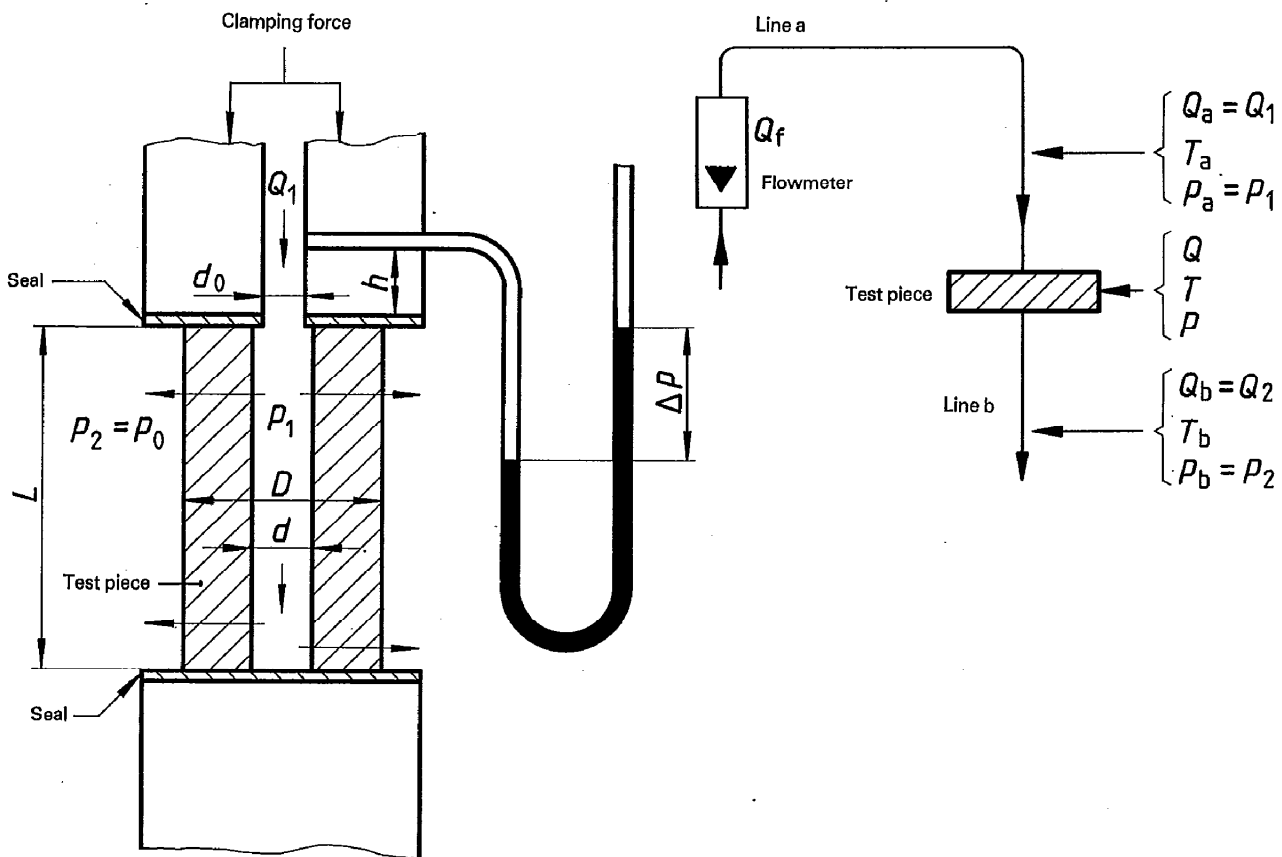
The permeability of hollow cylindrical test pieces is conveniently measured by clamping the cylinder axially between two flat surfaces and causing the test fluid to permeate outwards through the wall of the cylinder. An example is shown in figure 2. The flowmeter is placed upstream of the test piece. 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:

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

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

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

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

When the wall thickness  $\frac{D-d}{2}$  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:

$$\frac{\Delta p \times A}{e \times Q \times \eta} = \frac{1}{\psi_1} \times \frac{Q \times p}{A \times \eta} + \frac{1}{\psi_2}$$

[see annex A, equation (2)].

**ISO 4022 : 1987 (E)**

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

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

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

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  $10^{-12} \text{ m}^2$  ( $1 \mu\text{m}^2$ ) and the inertia permeability coefficient in  $10^{-6} \text{ m}$  ( $1 \mu\text{m}$ ), to an accuracy of  $\pm 5\%$  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

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

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)

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

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

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

where  $\psi_s$  is the permeability coefficient with slip flow present.

The correction for slip flow is given by

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

where

$\psi_s$  is the observed viscous permeability with slip flow present;

$\psi_v$  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.

## ISO 4022 : 1987 (E)

This relationship between  $\psi_s$  and  $\psi_v$  may be re-written in the form

$$\psi_s = B \times \psi_v \times \left( \frac{2}{p_1 + p_2} \right) + \psi_v \quad \dots (5)$$

Hence, by measuring  $\psi_s$  over a range of different pressures (i.e.,  $p_1$  and  $p_2$ ) by plotting  $\psi_s$  against  $\frac{2}{p_1 + p_2}$  a straight line is obtained. The slope of this line is equal to  $B \times \psi_v$ . The intercept of this line on the  $\psi_s$ -axis is equal to the viscosity permeability  $\psi_v$ .

The value of the Klinkenberg factor  $B$  increases with decreasing pore size, decreasing relative molecular mass, and increasing temperature and viscosity of the gas.

### A.4 Wall and end effects

Equation (2), relating to the flow of fluids, assumes that the porosity is uniformly continuous, whereas at the surfaces of a test piece discontinuities occur. There are two cases to consider:

- the wall effect for test pieces edge-sealed into a container;
- the end effect at the upstream and downstream surfaces of all test pieces.

In general with granular materials, if the diameter of the test piece is not less than about 100 times the diameter of the particles comprising the porous metal, the wall effect is usually negligible and with a test piece diameter of about 40 times the particle diameter, the error is less than about 5 %.

End effects are usually negligible when the test piece thickness is not less than 10 times the diameter of the particles comprising the porous metal. As in the case of the wall effect, the end effect also depends upon the difference between the porosity at the surface and the internal porosity.

### A.5 Long tubes of porous materials

Equation (2) (see A.2) and the calculation of area and thickness in 7.1.2, as well as the measurement of the pressure drop in 7.2, assume that the upstream pressure is uniform for all parts of the specimen. With long small bore tubes this assumption may not be valid. To establish that the error caused by the fall in pressure of the fluid along the bore of the tube is less than 5 %, the following procedures can be used:

- a) Insert a second pressure tapping at the end furthest from the fluid inlet, and compare this value with the value obtained from the pressure tapping nearest to the fluid inlet.
- b) Mask about half of the area of the tube from one end. Measure the permeability of this masked tube when the unmasked portion is
  - nearest to
  - farthest from

the fluid inlet end. Compare the two measured permeabilities.

## Annex B

### Test fluids

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

In the majority of cases, gases are more convenient test fluids than liquids. The problems with liquids are the following:

- it is more difficult to remove all solid particles which could be captured by the porosity of the porous metal and thereby change the permeability;
- dissolved gases may be precipitated within the pores, causing "gas locks" to occur;
- static heads of liquid may add difficulty in measuring the pressure drop;
- liquids are more expensive and messy to work with;
- some metals can have an adsorptive reaction with some liquids, whereby the pore size tends to be reduced;
- owing to capillary and surfactant effects, the degree of surface wetting of the pore surface by the liquid can effect the observed permeability, especially with porous metals of small pore size.

However, in rare cases liquids may be used where the permeability with respect to a specific liquid is required, provided that it is a Newtonian liquid and the following precautions are observed:

- the liquid must be free of solid particles and dissolved gases;
- the whole of the porous metal must be filled with the liquid and no pockets of gas shall be allowed to form either on the surfaces or in the pores of the porous metal test pieces.

In general, liquids will only give permeability results concordant with those obtained from gases when the pore size is large. For all these reasons, gases are the preferred test fluids.

However, with gases inertia losses are more likely to be present and hence equation (2) of annex A is more likely to be required.

ISO 4022 : 1987 (E)

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**UDC 669-138.8 : 539.217**

**Descriptors :** powder metallurgy, sintered products, porous metal, tests, determination, permeability.

Price based on 9 pages

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