CORESTA RECOMMENDED METHOD N° 40

DETERMINATION OF AIR PERMEABILITY OF MATERIALS USED AS CIGARETTE PAPERS, FILTER PLUG WRAP AND FILTER JOINING PAPER INCLUDING MATERIALS HAVING AN ORIENTED PERMEABLE ZONE.

(October 1994)

0. INTRODUCTION

A CORESTA Recommended Method N° 3 was published in 1976 and converted to ISO Standard 2965 in 1979. This method was applicable to materials which have a uniform distribution of permeability over their surface, such as cigarette paper (both inherently porous and randomly perforated over the whole area), reconstituted tobacco in sheet and plug wrap paper.

In 1991 CORESTA Method N° 18 was published and was applicable to materials having a narrow and oriented permeability zone such as perforated tipping paper.

Since 1992 various issues concerning the measurement of air permeability have been discussed within CORESTA. A Task Force was established to assess the effects of :

- sucking as opposed to blowing the air through the sample,
- varying the shape and measurement area of the test piece holder,
- varying ambient conditions *i.e.* temperature, relative humidity and atmospheric pressure,

on the measurement of paper permeability.
Experimental studies were conducted to assess each of these points.

The standard conditions used in the Paper and Board Industry, and adopted for this method, are given in ISO 187:1990 as:

Temperature : 23°C ± 1°C
Relative Humidity : (50 ± 2)% RH

In the Tobacco Industry, and particularly for manufactured cigarettes, the conditioning environment is 22°C ± 1°C and (60 ± 2)% RH (ISO 3402:1991).

An argument could have been made for conditioning cigarette paper under the same conditions used for conditioning cigarettes prior to smoking, especially as most cigarette manufacturers have this conditioning environment available.

Experiments have been conducted to determine the effect of using these two atmospheres on the measured paper permeability. These showed that there were no significant differences in data obtained under the two conditions, and it is clear that any differences which may exist must be small.

In laboratories, unable to use the standard conditions, it is permissible to use 22°C ± 1°C and (60 ± 2)% RH provided this is specified with the data report.

As a result, this Recommended Method was produced which replaces Method 3 published in 1976 and Method 18 published in 1991.

1. FIELD OF APPLICATION

This CORESTA Recommended Method :

- is applicable to the determination of the air permeability (*CU*) of materials used as cigarette papers, filter plug wrap and filter joining paper including materials having an oriented permeable zone.
- is applicable to papers having a measured permeability in excess of 10 *CU*.

Note : For an estimate of the air permeability of materials outside the scope of this Recommended Method, see the note under section 5.1 and section 7.5 note 2.

2. DEFINITIONS

For the purpose of this Recommended Method the following definitions apply.

2.1 *air permeability :* The flow of air (cm^3 min^{-1}) passing through 1 cm^2 surface of the test piece at a measuring pressure of 1.00 kPa.

The air permeability units are: cm^3 min^{-1} cm^{-2} at 1 kPa.

2.2 *measuring pressure :* Difference in pressure between the two faces of the test piece during measurement.

3. REFERENCES

CORESTA Recommended Method N° 21:1991
Atmosphere for conditioning and testing tobacco and tobacco products

ISO 3402:1991
Tobacco and tobacco products - Atmosphere for conditioning and testing

ISO 187:1990
Paper board and pulps - Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples.

4. PRINCIPLE

A test piece is held in a suitable device. A pressure difference is applied across the test piece. The resultant flow of air through the test piece is measured.

The principle of measurement is illustrated in figure 1A.

The air flow through the test piece may be produced by applying a positive or negative pressure to one side of the test piece. The direction of air flow through the test piece shall be that which would occur when the sample is used on the finished product, where known, *i.e.* from the outside face towards the inside face.

Notes:

1. If the air flow is produced by a positive pressure, the apparatus used shall incorporate a filter which protects the test sample from contamination by oil, water and particles.

2. With certain materials, the flow through the test piece may exhibit a non-linear relationship with applied pressure drop. Thus the air flow through the test piece is determined at two pressure differences to establish whether the flow / pressure relationship across the paper is linear or non-linear. If it is non-linear a second measurement of air flow is recorded at 0.25 kPa to characterise the material fully.

3. Dependent upon whether the volumetric air flow rate is measured up-stream or down-stream of the test piece, a difference of approximately 1% of the flow rate can exist either side of the theoretical value at the centre of the test piece.

5. APPARATUS

5.1 Test piece holder for clamping the test piece, free from leaks with a rectangular surface area, of $(2.00 \pm 0.02)\ cm^2$ with corner radii not greater than 0.1 cm. The long side (L) shall have a length of (2.000 ± 0.005) cm (see figure 1B).

Note : An estimate of the air permeability of speciality papers, outside the scope of this Recommended Method, may be required. In this case, specialised test piece holders with different surface areas may be necessary.

5.2 Pneumatic controller to produce an air flow at a given but adjustable pressure difference between the two mating faces of the test piece holder.

5.3 Pressure gauge suitable for measuring pressure differences to at least 0.001 kPa having a relative error of no more than 2% of the measured value within the measuring range.

5.4 Flow meter suitable for measuring the air flow with an error not greater than 5% of the measured value within the measuring range

5.5 Conditioning enclosure capable of maintaining the conditions given in ISO 187:1990. But see 7.2.

6. SAMPLING

Take a sample which is representative, on a statistical basis, of the population to be characterised.

Samples shall be free of visible defects and creases which may impair measurement performance.

7. PROCEDURES

7.1 *Leak check of the test piece holder.*

The procedure to be followed is given in annex A.

A leak check shall be performed daily, prior to use.

Air leaks between the mating faces of the test piece holder shall not be greater than

$2.0\ cm^3\ min^{-1}$.

A sketch of the assembly for estimating the leakage value is shown in figure 2.

Note: Some users require to determine the effect of surface leakage through particular papers which contribute to the measured flow. In this case if a value for leakage, with the test piece in place, is required, the procedure given in annex C may be used. This may be determined and referred to in the test report. It shall not be called air permeability.

7.2 *Preparation of the test pieces.*

Select at random from the sample taken in accordance with 6, the number of the test pieces required for the test plus an additional three test pieces to be used as described in 7.5 note 1.

If necessary make the test pieces suitable for testing (cut to the required dimensions, eliminate folds, seams etc.).

Condition the test pieces, prior to measurement, in a conditioning enclosure set at 23°C ± 1°C and (50 ± 2)% RH in accordance with ISO 187:1990. Samples shall be held such that the conditioning air has free access to all their surfaces.

In laboratories unable to use the conditions given in ISO 187:1990, the conditions 22°C ± 1°C and (60 ± 2)% RH given in CORESTA Recommended Method N° 21:1991 and ISO 3402:1991 may be used. In these cases a note shall be included with the test report.

Complete sample bobbins, where it is not possible to expose all surfaces to the conditioning atmosphere, may require an extended period of conditioning. The time required should be determined by practice and experience.

The period of time for conditioning is not given in this Recommended Method but shall be reported with the results.

7.3 *Calibration.*

Calibrate the instrument using the calibration standards and procedure referred to in annex B.

7.4 *Insertion of a test piece.*

All papers shall be placed in the test piece holder so that the measuring air will travel from the outside face towards the inside face of the paper as it is applied in the construction of the finished product, where this is known.

The positioning of the test pieces in the test piece holder is illustrated in figure 1A.

7.4.1 Materials with uniformly distributed permeability.

Place in such a way that, if possible, the centre of the smallest dimension (W) of the test surface is at the centre of the width of the test piece (see figure 1B).

7.4.2 Materials with a narrow and oriented permeable zone.

The permeable zone shall be oriented along, and parallel to, the direction of the 20 mm length of the test surface (see figure 1C).

The edges of the permeable zone shall not be less than 1mm from the edges of the test surface. Ideally the test piece should extend over each edge of the test surface by at least 3 mm. If for technical reasons this cannot be achieved, *i.e.* the specimen under study is less than 16 mm total width or the permeable zone is less than 4 mm from one edge of the sample, this shall be referred to in the test report.

7.5 *Measurement.*

Insert a test piece in the test piece holder. Establish an approximate pressure difference within the range (1.0 ± 0.05) kPa across the two faces of the test piece. Accurately record this pressure and the corresponding flow rate.

Note : The permeability of test pieces can vary throughout their length. For this Recommended Method the mean value of 10 individual measurements is used to determine the value of air permeability of a test piece. In practice laboratories often take a different number of measurements dependent upon the application of the measurement.

Proceed in the same way with all the test pieces.

The results are normalised as given in 8.1.

Notes :

1. If it is required further to characterise the material because it is believed that the flow/pressure relationship is non-linear perform the following test on three additional test pieces.

   Test for air flow rate/pressure relationships.

   Set up in turn pressure differences of 0.25 kPa and 1.00 kPa across the test material, without moving the test material. Record the corresponding air flow rates Q_1 and Q_2 ($cm^3\ min^{-1}$) across the test material respectively.

   Calculate the ratio *Y* by the formula: $Y = (Q_1 / Q_2) \times (1.0 / 0.25)$

   Repeat the above procedure on two other test pieces and calculate the mean of the three values obtained for the value *Y*. If the mean value of *Y* does not deviate by more than 2% from the value 1.00 (in practice if it is not greater than 1.02), the air flow rate/ pressure relationship is linear. Otherwise the relationship is referred to as non-linear.

   If the test material has been shown to have non-linear air flow rate/pressure characteristics, the measurement of air flow rate at a single pressure difference is considered inadequate to characterise the material. The flow rate may be determined using the second pressure difference of 0.25 kPa.

   Further information is given in Annex D.

2. Materials that exhibit a linear characteristic having a permeability of less than 10 *CU* may be re-measured in order to obtain an estimate of permeability using:

   - a test piece holder with a single larger test surface area,

   - a test piece holder containing multiple areas that perform simultaneous measurements of the standard single 2.00 cm^2 rectangular test surface area, each with dimensions described in 5.1,

   -a pressure drop of 2.0 kPa.

   The method used must then be stated with the estimate of permeability.

7.5.1 *Measurement of strips.*

Make ten consecutive measurements with a minimum distance of 20 mm between measurements.

7.5.2 *Measurement of spills (papers recovered from manufactured products).*

Make ten measurements comprising single measurements on each of ten spills. Ensure that the overlap seam is not included in the test surface.

8. EXPRESSION OF RESULTS

8.1 *Normalisation of air flow.*

The determination of the value of air permeability shall be the mean value from the individual measurements: see 7.5.1 and 7.5.2.

Note : If a measuring head with multiple test surfaces is used as described in 7.5 note 2, it must be understood that the measurement obtained is already an average of the number of test surfaces used in the measuring head. In addition, care must be taken in the interpretation of r & R when using these measuring heads.

The air permeability, *CU*, is expressed in cubic centimetres per minute per square centimetre measured at 1 kPa. Using a 2 cm^2 test surface it is given by formula :

$$CU = Q\ (cm^3\ min^{-1}) / 2$$

where :

CU is the value of air permeability.

and :

Q is the air flow, in cubic centimetres per minute, passing through the test piece.

In practice, *Q* is not measured at precisely 1 kPa and a normalisation procedure to correct to 1 kPa is required. In addition, other measuring heads, with areas not 2 cm^2 may have been used (see 7.5 note 2) and a correction for this is then also required.

The general formula is as follows :

$$CU = [Q\ (cm^3\ min^{-1}) / A\ (cm^2\ )] \text{ x } [\ 1\ (\text{kPa}) / d\ (\text{kPa})]$$

where :

CU is the value of air permeability.

Q is the air flow, in cubic centimetres per minute, passing through the test piece.

A is the surface area, in square centimetres of the test piece subjected to testing.

d is the actual measurement pressure difference, in kilopascals, across the two surfaces of the test piece.

9. REPEATABILITY AND REPRODUCIBILITY

The difference between two single results found on matched test samples by one operator using the same apparatus within the shortest feasible time interval will exceed the repeatability value (r) on average not more than once in 20 cases in the normal and correct operation of the method.

Single results on matched test samples reported by two laboratories will differ by more than the reproducibility value (R) on average not more than once in 20 cases in the normal and correct operation of the method.

A major international collaborative study, involving 24 laboratories and 6 samples, conducted in 1994 showed that when cigarette papers, filter plug wrap and filter joining paper including materials having an oriented permeable zone are measured in accordance with this method, the following values for repeatability (r) and reproducibility (R) were obtained.

TABLE 1

Mean air permeability units CU	Repeatability conditions (r)	Reproducibility conditions (R)
26.9	2.37	6.01
49.2	4.15	8.37
221	17.4	26.3
1334	96.6	133
2376	281#	326
21449	1182	2077

See note at bottom of next page

For the purpose of calculating r & R one test result is defined as the mean value obtained from ten measurements from a single paper strip or the mean value obtained from ten separate paper spills removed from manufactured products.

These values for r & R may only be valid for the particular papers used. It is not practical, in the context of collaborative studies, to conduct repeat tests on the same test piece. Therefore the inhomogeneity in the test pieces contributes to the within laboratory variance. This situation is referred to in ISO 5725:1986, section one, 4.2.4. which is quoted below :

"When tests have to be performed on solid materials that cannot be homogenised (such as metals, rubber or textile fabrics) and when the tests cannot be repeated on the same test piece, inhomogeneity in the test material will form an essential component of the precision of the measurement and the idea of identical material no longer holds good. Precision experiments can still be carried out, but the values of r and R may only be valid for the particular material used and should be quoted as such. A more universal use of r and R will be acceptable only if it can be demonstrated that the values do not differ significantly between material produced at different times or by different producers. This would require a more elaborate experiment than has been considered in this International Standard."

From the data obtained in the collaborative experiment it is possible to estimate the within laboratory component of variance with the day-to-day and strip to strip components of variance removed. This within laboratory component of variance can then be used to derive alternative values for repeatability. These and the corresponding values for reproducibility are shown in the following table.

These values have been adjusted to be equivalent to values that might have been obtained from a similar analysis of the mean of ten readings replicated within a single strip.

TABLE 2

Mean air permeability units CU	Repeatability conditions (r)	Reproducibility conditions (R)
26.9	1.57	5.72
49.2	3.12	7.89
221	11.7	22.9
1334	45.2	95.1
2376	249#	297
21449	519	1773

(#) From the results of the analysis in tables 1 & 2 it can be seen that, in general, both r & R, when compared as a percentage of their mean value, are highest for the lower permeability papers, with a tendency for r & R, when expressed as a percentage of the mean, to decrease as the mean permeability increases.

This paper however, exhibits results which do not conform to this trend. An examination of Table 1 Shows that the high value of R% for this paper (when compared with the other papers) is entirely due to the high value of the within laboratory variability for this paper. There is no evidence to suggest that the between laboratory variability is any higher for this paper (in terms of the percentage of the mean) than for any of the other papers tested in this study.

This was confirmed in the analysis by the within and between laboratory standard deviations. The values of the within-laboratory percentage standard deviation of the mean, display the same pattern as the values of r% (as expected) but the values for between-laboratory percentage standard deviation of the mean, do not indicate an unexpectedly high value for this paper.

The results for this paper demonstrate that the values for r & R obtained from this study may only be applicable to the papers tested in this study.

10. TEST REPORT

The test report shall show the method used and the results obtained. It shall also mention any operating conditions not specified in this Recommended Method, or regarded as optional, as well as any circumstances that may have influenced the results.

The test report shall include all details required for complete identification of the sample. Specifically the test report shall contain:

a. Date of measurement;

b. Date of sampling and sampling method;

c. Identification and full description of the material tested, stating the properties (nature, width,...) of samples having oriented zone permeability;

d. Precise and full measuring conditions, particularly those deviating from this Recommended Method and any events which are likely to have affected the results;

e. The conditioning atmosphere and period of conditioning time;

f. Barometric pressure at the time of testing;

g. Results in air permeability units (*CU*);

h. Elementary statistics relating to the results;
   - number of measurements;
   - mean and standard deviation values.

ANNEX A

LEAK TESTING OF TEST PIECE HOLDER

(This annex forms an integral part of the Recommended Method)

A.1. *Definition of leakage.*

Air flow unintentionally aspirated from the surrounding atmosphere or escaping into it through the sealing surface of the test piece holder and elsewhere.

A.2. *Determination*.

The performance testing of instruments for measuring air permeability of materials used as cigarette papers, filter plug wrap and filter joining paper (including materials having an oriented permeable zone) shall be conducted in accordance with manufacturers instructions.

However, the following describes a general test for assessing the value of any leakage of air between the mating faces of the measuring head assembly.

a. Seal the air flow path to atmosphere from the measuring head assembly.

b. Operate the instrument in the normal manner to make an air permeability measurement ensuring that no sample has been placed between the mating faces of the test piece holder clamp assembly.

c. Record the leakage rate as indicated by the instrument. The mating faces of the measuring head clamp assembly, shall seal such that a flow measurement of not greater than 2 cm^3 min^{-1} is recorded.

d. Repeat this procedure five times. If any value is greater than 2 cm^3 min^{-1} the clamp assembly is deemed to be defective.

e. The readings shall be noted and reported with any test results.

The principle of measuring the test piece holder clamp assembly leakage is illustrated in figure 2.

ANNEX B

CALIBRATION OF AIR PERMEABILITY STANDARDS & AIR PERMEABILITY MEASURING INSTRUMENTS

(This annex forms an integral part of the Recommended Method)

B.1. *Essential Properties of Calibration Standards.*

Air Permeability Calibration Standards are used to calibrate measuring instruments for the determination of air permeability of materials used as cigarette papers, filter plug wrap and filter joining paper (including materials having an oriented permeable zone).

The calibration standard shall have a known and repeatable value of volumetric air flow as measured at the exit of the standard, when subjected to a specified (1 kPa) static pressure. The flow/pressure characteristic of the standard shall remain constant and shall be largely unaffected by changing atmospheric conditions.

The calibration standard shall be inscribed with the value of volumetric air flow (at 1 kPa) quoted to a minimum accuracy of 0.5%.

The precise construction of these calibration standards depends upon the design of the air permeability meter in which they are to be used.

B.2. *Procedure For Calibration of Standards.*

The laboratory testing atmosphere shall be controlled to ISO 187:1990.

The standard shall be held in a calibration holder, the mechanical arrangement of which shall not alter the characteristics of the standard.

The air flow through the calibration standard may be produced by applying a negative pressure to one side of the calibration holder. The direction of air flow through the calibration standard shall be that which would occur when it is used to calibrate an air permeability measuring instrument.

The volumetric air flow at the exit (low pressure side) of the calibration holder, containing the calibration standard, shall be measured.

A schematic diagram of a typical calibration holder is illustrated in figure 3.

B.2.1 *Method 1*

The flow shall be adjusted such that a constant pressure of (1.000 ± 0.005) kPa is applied across the standard. Using a gas calibrator, that does not generate a systematic influence on the flow measurement, measure the volumetric flow at the exit of the standard.

Repeat this procedure five times with each calibration standard to be calibrated. The value to be ascribed to the calibration standard shall be the mean of these five values.

B.2.2 *Method 2*

Using a gas calibrator that does not generate a systematic influence on the flow measurement, measure the volumetric flow at the exit of the standard.

A minimum of two measurements shall be made with the flow adjusted such that a constant pressure is maintained, in turn, at 5% to 10% above 1 kPa and at 5% to 10% below 1 kPa. At each point the corresponding pressure drop across the standard shall be recorded to the nearest 0.005 kPa. These measurements are used to interpolate the precise value of volumetric air flow exiting the standard, at 1 kPa.

B.3. *Procedure For Calibration of Instruments.*

The calibration and performance testing of instruments for measuring the air permeability of materials used as cigarette papers, filter plug wrap and filter joining paper including materials having an oriented permeable zone should be conducted in accordance with the manufacturer's instructions.

B.4. *Principle*.

To obtain best accuracy the instrument shall be calibrated over its specified range of measurement. Calibration shall be undertaken at measurement values corresponding to individual transducing elements used to achieve the instrument's measurement range.

B.5. Follow the procedure given in the instrument manufacturer's instruction. A typical procedure would be :

a. Install the calibration standard and allow it to equilibrate with the temperature of the measuring air.

b. Connect a reference manometer into the measuring circuit to monitor the pressure drop applied across the calibration standard. The maximum relative error of the reference manometer shall be less than 0.5% for measured value.

c. Establish an approximate pressure difference within the range (1.0 ± 0.1) kPa across the calibration standard.

d. Adjust the instrument's measurement system to display the exact value indicated on the reference manometer.

e. Disconnect the reference manometer and seal the connection point.

f. Adjust the pressure drop across the calibration standard to (1.000 ± 0.005) kPa and adjust the instrument's measurement system to display the value inscribed on the calibration standard.

g. Repeat f. for each of the calibration standards.

h. Return the instrument to its measurement mode and make an air permeability measurement on each of the calibration standards to check that the measurement is within the tolerances of calibration of the calibration standards and the measurement specification of the instrument.

ANNEX C

DETERMINATION OF RELEVANT SURFACE LEAKAGE OF TEST PIECE IN THE TEST PIECE HOLDER

(Informative, this annex does not form an integral part of the Recommended Method)

C.1. *Definition.*

The air flow aspirated from the surrounding atmosphere, or escaping into it, unintentionally through the sealing surface of the test piece holder.

C.2. *Determination*.

The principle of measurement of relevant surface leakage is illustrated in figure 4.
The determination of the relevant surface leakage can be carried out as follows :

a. Connect a calibrated syringe to the inlet side of the test piece holder.

b. Connect a pressure measuring device to the junction of the syringe and the inlet side of the test piece holder, ensuring that all connections are air tight.

c. Insert a sample of the test material to be measured and a non-permeable membrane covering the whole test area, including the sealing surfaces, in the test piece holder. Ensure that the test material faces the inlet cavity of the test piece holder. The non-permeable membrane ensures that only that part of the total leak relevant to the determination of air permeability is considered.

d. Close the test piece holder and apply weights to the syringe to create a pressure of approximately 1 kPa to the upper cavity of the test piece holder.

e. Measure the leakage flow by timing the change in position of the piston in the syringe. A suitable length of time should be chosen such that an accurate assessment of surface leakage is possible.

f. The pressure at the inlet side of the test piece holder should be monitored throughout this time and should remain close to 1 kPa.
Any change in pressure may indicate unacceptable resistance in the syringe, in which case the test should be repeated.

Note :

This test may also be performed omitting the non-permeable membrane and sealing the outlet of the test piece holder.

ANNEX D

THE FLOW OF AIR THROUGH POROUS MATERIALS

(Informative, this annex does not form an integral part of the recommended Method)

D.1. *Theoretical considerations.*

The flow of air through a porous material is dependent on both viscous and inertial forces in the flowing air. The total flow of air through the material may be expressed as:

$$Q = ZAP + Z'AP^{n} \qquad (1)$$

where :

Q is the total air flow, $cm^3\ min^{-1}$,

A is the area of the material (cm^2) exposed to the flowing air,

P is the pressure difference across the material (kPa),

Z is the component of air permeability of a porous material due to viscous forces ($cm^3\ min^{-1}\ cm^{-2}\ kPa^{-1}$)

Z' is the component of air permeability of a porous material due to inertial forces ($cm^3\ min^{-1}\ cm^{-2}\ kPa^{-1/n}$)

and :

n is a constant whose value lies between 0.5 and 1.0, and is dependent on the size distribution of the spaces/holes in the material through which the air flows.

The general form of equation 1, as written, has a non-linear relationship between air flow (Q) and pressure difference (P). Since the air permeability of material is defined as the flow of air through 1 cm^2 of the material when the pressure difference across it is 1.00 kPa, then from equation 1 the "total air permeability" of the material is equal to ($Z + Z'$).

Two extreme forms of equation 1 can be considered :

(i) With porous cigarette paper, for example, spaces in the material are small (typically 1 µm wide) compared to paper thickness (20-40 µm). Inertial forces in the air flow are negligible, $Z' = 0$, and equation 1 reduces to :

$$Q = ZAP \qquad (2)$$

In this case the relationship between air flow (Q) and pressure difference (P) is linear.

(ii) With perforated tipping paper, for example, the diameter of the perforation holes may be large (*e.g.* above 100 µm) compared to the paper thickness (*e.g.* 40 µm). In this case n = 0.5 and equation 1 becomes quadratic:

$$Q = ZAP + Z'A\sqrt{P} \qquad (3)$$

If there are no spaces in the tipping paper, other than the perforation holes, then $Z = 0$ and equation 3 reduces to :

$$Q = Z'A\sqrt{P} \qquad (4)$$

D.2. *Characterisation of materials having non-linear air flow/pressure relationship.*

If the test material has been shown to have non-linear air flow rate/pressure characteristics, the values of Z, Z' and n can be calculated using the above equations from a regression of values of Q determined at a series of values of P.

As a minimum, the material should be characterised by two values of air flow rate, determined for pressure differences of 0.25 and 1.00 kPa.

D.2.1 A more general form of equation 1 is :

$$Q = Z_T \; A \, P^{k} \qquad (5)$$

where :

Z_T is the total air permeability of the paper

and :

k is a constant whose value lies between 0.5 and 1.0, dependent on the size distribution of the spaces/holes in the material through which the air flows.

The constant k can be determined using equation 5 if the resulting air flows are measured for two different measuring pressures:

$$k = [\log (Q_1 / Q_2)] / [\log(P_1 / P_2)] \qquad (6)$$

where :

Q_1 is the air flow ($cm^3 \, min^{-1}$) measured at P_1 ,

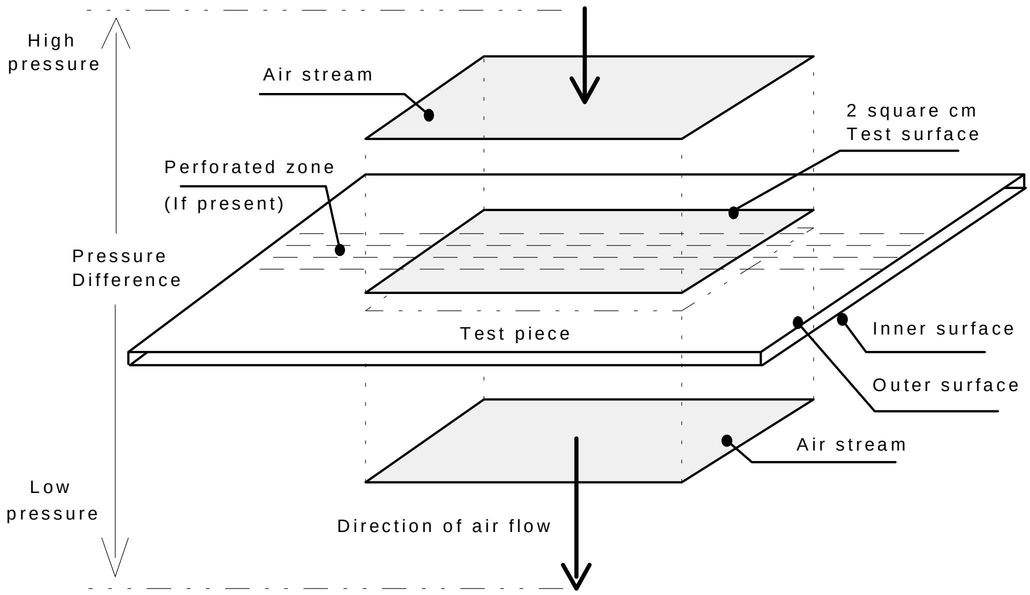
Q_2 is the air flow ($cm^3 \, min^{-1}$) measured at P_2,

For small differences between actual and nominal measuring pressure, the air flow may be calculated by means of the following equation without giving rise to appreciable error :

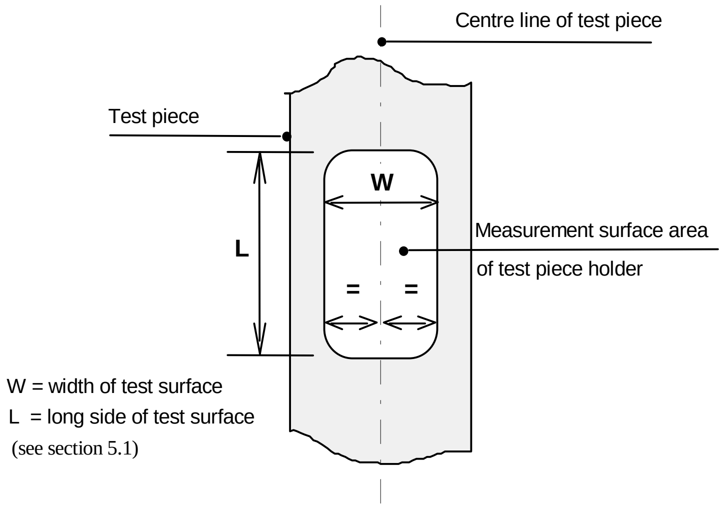
$$Q_2 = \frac{P_2^k}{P_1} \qquad (7)$$

FIGURE 1

A. PRINCIPLE OF MEASUREMENT



B. POSITIONING OF TEST PIECES FOR MATERIALS WITH UNIFORMLY DISTRIBUTED PERMEABILITY



C. POSITIONING OF TEST PIECES FOR MATERIALS WITH A NARROW AND ORIENTED PERMEABLE ZONE

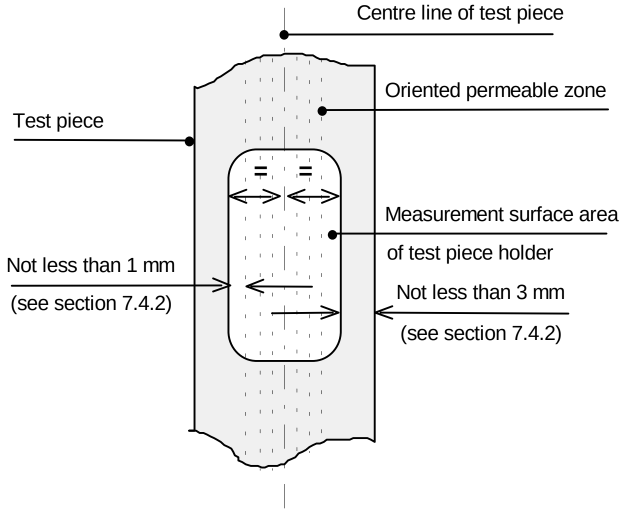


FIGURE 2

Leak testing of test piece holder (principle)

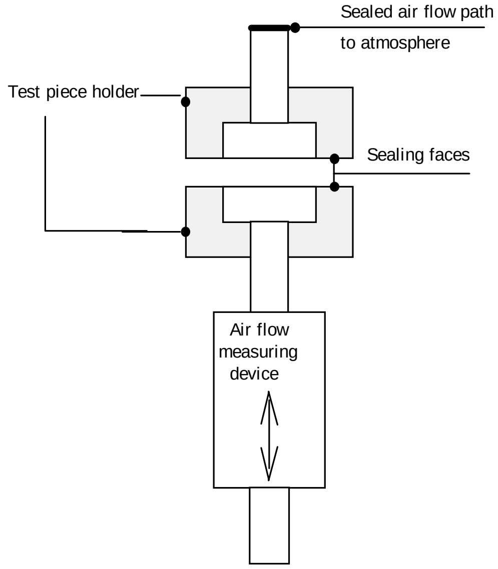


FIGURE 3

Apparatus for calibration of standards (Schematic)

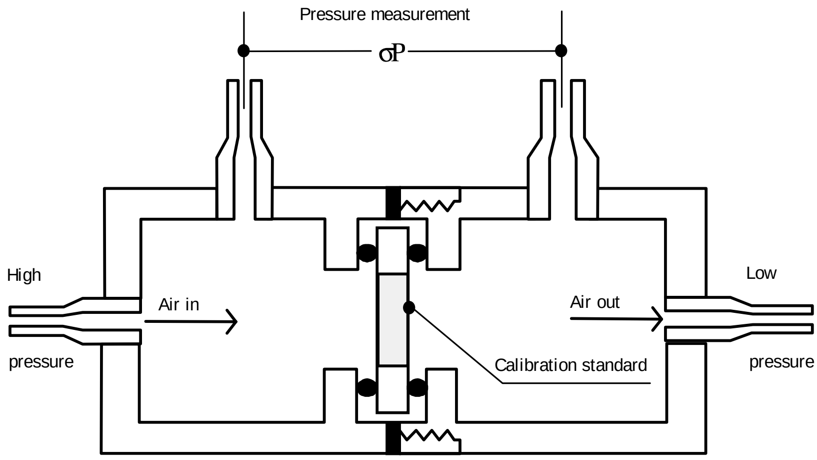


FIGURE 4

Measurement of surface leakage