CORESTA RECOMMENDED METHOD N° 41

DETERMINATION OF THE DRAW RESISTANCE OF CIGARETTES AND FILTER RODS

(June 2007)

0. INTRODUCTION

The draw resistance of cigarettes and filter rods is a very widespread and important concept both for product quality specifications and for analytical determinations by mechanical smoking.

Different procedures and apparatus are currently available for the determination. It has so far not been possible to standardise the complete description of the equipment to be used and the detailed procedure. Nevertheless, it has been possible to obtain a broad consensus on the definitions to be adopted and the conditions that allow comparable determinations of this characteristic to be made.

One of the major conditions to achieve this is the use of pressure drop transfer standards to calibrate the instruments (see Appendices 1 and 2).

1. SCOPE AND FIELD OF APPLICATION

This method defines the draw resistance of cigarettes and filter rods and specifies standard conditions for its determination.

It applies to cigarettes, filter rods and, by extension, to cylindrical tobacco products similar to cigarettes.

2. REFERENCES

1. *ISO 3308:2000*
   Routine analytical cigarette-smoking machine - Definitions and standard conditions.
2. *ISO 3402:1999*
   Tobacco and tobacco products - Atmospheres for conditioning and testing.
3. *CORESTA Recommended Method N° 21: 1991*
   Atmosphere for conditioning and testing tobacco and tobacco products.
4. *Beiträge zur. Tabakforschung International 21/3 (2004) 167-174 (www.beitraege-bti.de).*
   "Compensation for the effects of ambient conditions on the calibration of multi-capillary pressure drop standards", S. Colard, W. Trinkies, G. Cholet, B. Camm, M. Austin and R. Gualandris
5. *CORESTA Guide N° 4 - June 2007*
   A user guideline for the measurement of pressure drop of cigarettes and cigarette filter rods.

3. DEFINITIONS

3.1. *Draw resistance of a cigarette or filter rod:* the static pressure difference between the two ends of the specimen when it is traversed by an air flow under steady conditions in which the volumetric flow is 17,5 ml s^{-1} at the output end.

3.2. *Input end:* the end of the specimen intended to be lit in the case of cigarettes.

3.3. *Output end:* the opposite end to the input end.

3.4. *Standard direction of flow:* the direction from the input end to the output end.

3.5. *Transfer Standard:* standard used as intermediary to compare standards

3.6. *Pressure Drop Transfer Standard:* a transfer standard for pressure drop measurement systems. A pressure drop transfer standard is calibrated under standard ambient conditions and used under local ambient conditions. (The form and properties of suitable transfer standards are given in Appendix 2 of this recommended method).

3.7. *Dummy standard:* a device with the same shape and similar form to a pressure drop transfer standard, for use in leak testing of calibration apparatus (see 4.2.2.2). A suitable dummy standard consists of a pressure drop transfer standard or a smooth metal tube of similar dimensions.

3.8. *Reference Standard:* a pressure drop transfer standard against which other pressure drop transfer standards are compared. (Such a reference standard is generally reserved for this purpose and is not used for the routine calibration of pressure drop measuring instruments).

3.9. *Monitor Reference Standard:* a reference standard used to confirm the correctness of calibration of an instrument or measurement system (see Appendix 2; 4.2.2.3)

4. TESTING CONDITIONS FOR THE DETERMINATION

4.1. *Testing conditions common to cigarettes and filter rods*

4.1.1. The testing conditions shall be constant and in agreement with the conditions under which the calibration was performed (see section 5).

4.1.2. Air Flow

The air flow shall be from the input end in the standard direction of flow (3.4).

4.1.3. Position

Products with cavities containing loose fill material shall be positioned vertically.

4.2. *Conditions particular to cigarettes*

4.2.1. Insertion of the specimen

The output end of the specimen shall be inserted into a measurement device encapsulated to a depth of 9 mm.

4.3. *Conditions particular to filter rods*

4.3.1. Encapsulation

The specimen shall be completely encapsulated in a measuring device so that no air can pass through the filter rod wrapping.

5. CALIBRATION OF THE INSTRUMENTS

The instrument shall be calibrated before normal testing using transfer standards. This shall be done at least once per day. The calibration shall be done in accordance with Appendix 1.

The instrument shall be recalibrated if the atmospheric conditions change by more than 2 °C for temperature and/or 5% for relative humidity.

Each calibration of the instrument shall be recorded for later reference.

6. PROCEDURES FOR MEASUREMENT

Note: A CORESTA Guideline (see reference 5 in section 2) is available, which describes the best practice for the measurement of pressure drop, so as to consistently obtain the most accurate and most reliable measurements despite the many external influences that can affect the measured value.

6.1. *Conditions common to vacuum and pressure instruments*

The specimen shall be inserted into the measuring device of the instrument (either manually or automatically) and the reading for the draw resistance shall be recorded.

6.1.1. Conditions particular to vacuum instruments

Before the reading of the draw resistance is taken, the specimen shall be left in the measuring device until the measurement settles.

Note: Practice has shown that a settling time of 4 to 6 seconds is normally sufficient.

6.1.2. Conditions particular to pressure instruments

For pressure instruments the reading is dependent on time. The settling time is dependent on the draw resistance of the specimen tested. The required settling time therefore has to be determined depending on the draw resistance of the specimen and the type of instrument. The reading for draw resistance shall be taken at a constant time after the insertion of the specimen.

Note: Practice has shown that for lower draw resistances (below 200 mmWG) a settling time of 2 to 3 seconds is sufficient while for higher draw resistances (above 400 mmWG) the settling time should be adjusted to 4 to 6 seconds. The settling time shall be mentioned in the test report.

7. TEST REPORT

The test report shall show the method used and the results obtained. It shall also mention any operating conditions not specified in the present Method. The test report shall include all details required for the complete identification of the sample.

7.1. *Characteristic data about the specimen*

- Product name or identification;
- Date of sampling.

7.2. *Description of test*

- Date of test;
- Type of instrument used;
- Total number of specimens tested;
- Room temperature (in degrees Celsius) during testing;
- Relative humidity (in percent) during testing.

7.3. *Test results*

The expression of the laboratory data depends on the purpose for which the data are required and the level of laboratory precision. It is recommended that :

- the average draw resistance is expressed to the nearest 1 mmWG;
- the standard deviation of the draw resistance of the specimen is expressed to the nearest 0,1 mmWG.

8. REPEATABILITY AND REPRODUCIBILITY

A major international collaborative study involving 21 laboratories and 6 samples for cigarettes as well as 6 samples for filter rods conducted in 1994 showed the following values for repeatability (r) and reproducibility (R) of this Method (see also Appendix 3).

Cigarettes:

r = 2,3 mmWG
R = 5,8 mmWG

These values are valid for a pressure drop range of 40 mmWG to 130 mmWG.
The difference between two single results found on identical test material (cigarettes) by one operator using the same apparatus within the shortest feasible time interval will exceed the repeatability value of r = 2,3 mmWG on average not more than once in 20 cases in the normal and correct operation of the method.

Single results on identical material (cigarettes) reported by two laboratories will differ by more than the reproducibility value of R = 5,8 mmWG on average not more than once in 20 cases in the normal and correct operation of the method.

Filter Rods:

r = 0,0072 x m

R = 0,023 x m

m : mean value of pressure drop in mmWG

These values are valid for a pressure drop range of 200 mmWG to 700 mmWG.

The difference between two single results found on identical material (filters) by one operator using the same apparatus within the shortest feasible time interval will exceed the repeatability value r = 0,0072 x m on average not more than once in 20 cases in the normal and correct operation of the method.

Single results on identical material (filters) reported by two laboratories will differ by more than the reproducibility value R = 0,023 x m on average not more than once in 20 cases in the normal and correct operation of the method.

For the purpose of calculating r and R one test result was defined as the mean draw resistance obtained from measuring 30 specimens.

APPENDIX 1

CALIBRATION OF DRAW RESISTANCE INSTRUMENTS USING PRESSURE DROP TRANSFER STANDARDS

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

Calibration of Instruments

The calibration and performance testing of instruments for measuring the draw resistance of cigarettes and cigarette filter rods should be conducted in accordance with manufacturer's instructions.

1. *Principle*

To obtain best accuracy the instrument should be calibrated as close as possible to its full scale deflection or at the extreme end of the measurement range of products to be tested.

To check for air leaks that could have been present during calibration, and/or linearity of the measurement system, at least one intermediate value pressure drop standard should be used to check a mid point measurement value.

If preferred, or in addition to the mid point check, a calibration check can be made with a pressure drop standard having a nominal pressure drop value close to the draw resistance of the specimens to be measured.

2. *Method*

The transfer standard should be inserted into the measuring head in accordance with method described by the instrument manufacturer, and allowed to equilibrate to the temperature of the measuring air. When the instrument reading is stable continue with calibration procedure.

(a) In the case of vacuum (sucking) based instruments with the volumetric flow of 17,5 ml s^{-1} established by a critical flow orifice (CFO), it is not possible to adjust the flow. In this case the electronic display should be adjusted to read the value inscribed on the transfer standard.

(b) In the case of pressure (blowing) instruments incorporating a flow controller an external manometer should be coupled to the pneumatic measurement circuit and the flow controller should be adjusted until the manometer registers the value inscribed on the transfer standard.

The electronic display should then be adjusted to read the value inscribed on the transfer standard.

(c) In the case of liquid column (blowing) instruments the liquid zero should first be adjusted to the zero mark on the scale. The standard should then be introduced to the instrument and allowed to equilibrate. When the reading is stable the flow controller should be adjusted until the manometer registers the value inscribed on the transfer standard.

APPENDIX 2

CALIBRATION OF PRESSURE DROP TRANSFER STANDARDS

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

1. *Calibration of Pressure Drop Transfer Standards*

(**Note:** All uncertainty values quoted in this appendix are given at 95% confidence level)

Pressure drop transfer standards have defined pressure drop values, which can be used to calibrate measuring instruments for the determination of draw resistance of cigarettes and pressure drop of cigarette filter rods.

The certified value of the pressure drop standard is the calibrated value adjusted by means of a compensation formula that normalises the calibrated value to standard ambient conditions in accordance with ISO 3402 which are given as 22 °C; 60 % RH; 1013 mbar.

The derivation and application of this compensation formula is given in Appendix 5.

2. *Essential properties of Pressure Drop Transfer Standards*

(**Note:** Although different types of pressure drop standards are available, this appendix refers specifically to standards with 10 capillaries and made from glass. In particular, the application of the compensation formulae given in Appendix 5 and the values of r & R quoted are specific to glass multicapillary standards. Other values of r & R and other compensations may be appropriate for standards of different construction).

Pressure drop transfer standards shall exhibit the following properties:

a) They shall be made of a chemically inert material which is unaffected by use or ageing.

b) They shall closely resemble the physical size and shape of a filter rod or cigarette.

c) They shall have defined and repeatable values within stated confidence limits.

d) The airflow through the pressure drop standard shall be laminar and shall have repeatable measurement characteristics.

e) The level of uncertainty of the certified value of pressure drop transfer standards shall not exceed 1 % of its absolute value.

3. *Calibration Apparatus*

3.1. Holder for standard under test

To determine the pressure drop of a glass multicapillary transfer standard it shall be placed in a holder, the mechanical arrangement of which shall not modify the characteristics of the standard nor create any systematic influences upon the calibrated value. The essential qualities of a typical arrangement are illustrated in Figure 1.

3.2. Determination of volumetric flow

A volumetric flow measurement device (VFMD) that does not generate any systematic influence on the flow measurement is used to determine the time taken for a volume displacement of air to be drawn through the standard under test.

The VFMD shall have a maximum uncertainty of 0,3 % of indicated volume.

Note: Refer to reference 4 for information on specified limits of uncertainty.

The following are two examples of volumetric flow measurement devices:

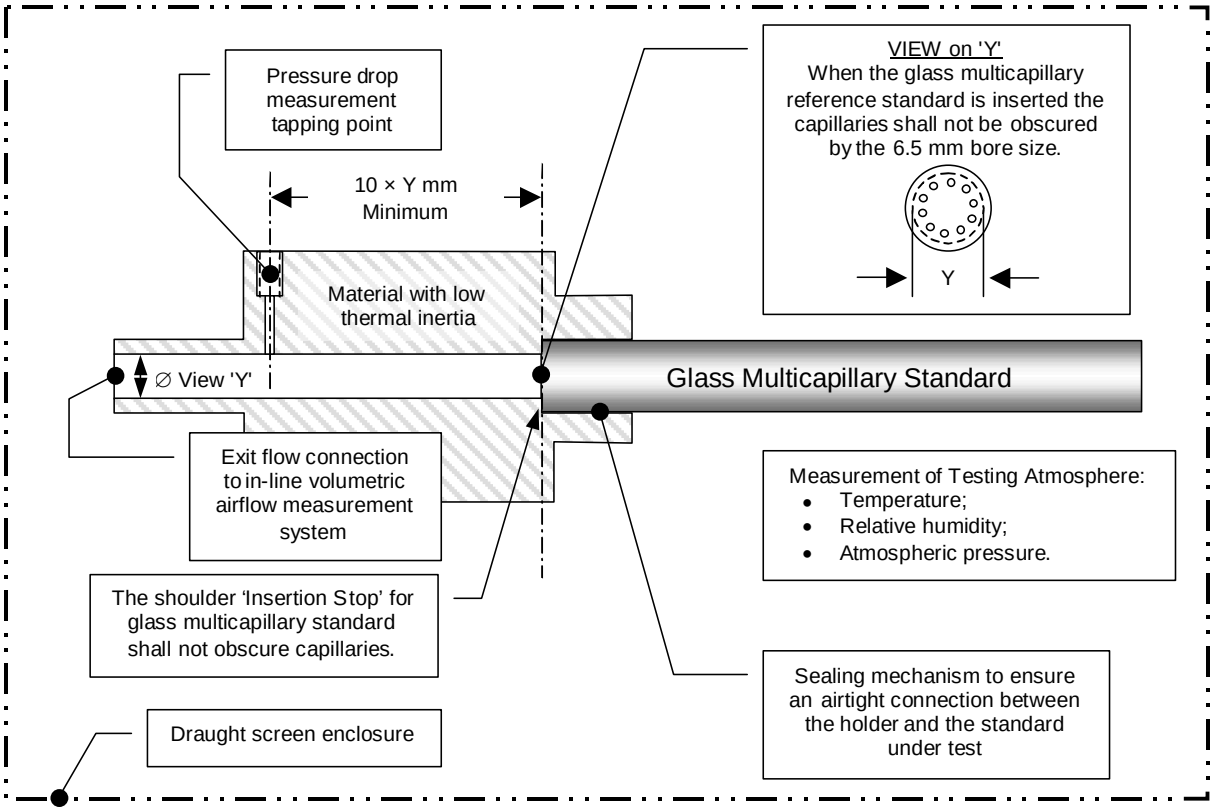


Figure 1 - Essential Qualities of Calibration Device

3.2.1. Piston driven

This device takes the form of a precision bore cylinder inside which a piston is moved at a constant speed by a precision motor to draw a constant volumetric flow, through the standard under test, from atmosphere.

3.2.2. Vacuum driven

This device takes the form of a precision bore cylinder having a free moving piston which is moved vertically upward by the application of a separate suction source applied to the out-flow of the cylinder. This apparatus has sensors that monitor the movement of the piston to allow a precise measurement of the time to displace a known volume of air, which has been drawn through the standard under test from atmosphere and which collects under the piston.

3.3. Measurement of air temperature, relative humidity and atmospheric pressure.

The temperature and relative humidity of the measurement air shall be measured at a point in close proximity to the air entering the standard, within the confines of the draught screen enclosing the standard under test.

The atmospheric pressure measurement shall be made within the testing environment and recorded at the same time as the temperature and relative humidity measurements.

3.3.1. The temperature measurement shall have a maximum uncertainty of 0,3°C.

3.3.2. The relative humidity measurement shall have a maximum uncertainty of 5 %

3.3.3. The atmospheric pressure measurement shall have a maximum uncertainty of 100 Pa

Note: Refer to reference 4 for information on specified limits of uncertainty.

3.4. Pressure measurement system

A differential pressure measurement system shall be connected to the tapping point of the holder to measure the pressure difference between the exit end of the standard and atmosphere, while the standard is traversed by the controlled airflow under steady conditions.

This pressure difference shall be measured and recorded.

The pressure measurement system shall have a maximum uncertainty of 0,2 % of the measured value.

3.5. Suction source

A suction source, as required in 3.2 and capable of drawing a constant volumetric airflow, shall be placed in–line with a VFMD which is, in turn, connected to the exit flow connection of the holder

A typical arrangement of the calibration apparatus is illustrated in Figure 2.

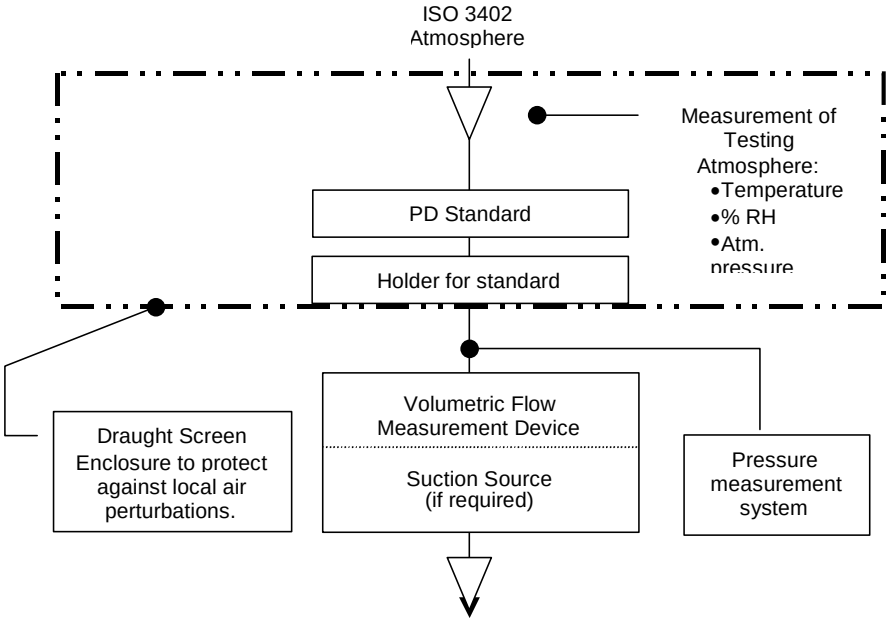


Figure 2 – Typical Arrangement of Calibration Apparatus

4. *Calibration Procedure*

4.1. Cleaning of standards

Before calibration, all standards shall be cleaned by immersion in an ultrasonic bath containing a solution of distilled water and 5% non-ionic surfactant solvent.

(**Note:** Two examples of non-ionic surfactant solvents are Igepal CO 630® (Nonylphenol Ethoxylate) and Branson GP® concentrated cleaning formula).

4.1.1. The standards shall be submerged in the cleaning vessel in the cleaning solution for a minimum time of 10 minutes with their longitudinal axis between 10° and 20° from vertical to ensure that any contact with the floor of the cleaning vessel will be on the edge of the standard thereby avoiding any possible contamination of the capillaries.

4.1.2. Following the cleaning process the standards shall be submerged and rinsed in an ultrasonic bath containing pure distilled or deionised water (free from dissolved salts and other compounds) for a minimum time of 5 minutes.

4.1.3. The standards shall then be dried, ensuring that no residual water deposits remain in the capillaries and the possibility of the ingress of contamination is minimised.

4.2. Pre Calibration Procedures

Measurements shall be conducted in a testing atmosphere in accordance with ISO 3402 and the calibration apparatus shall be configured in accordance with the arrangement illustrated in figure 1.

4.2.1. Equilibration of Standards

The calibration apparatus and pressure drop transfer standards awaiting tests shall be left open to the testing atmosphere for a minimum of 12 hours to ensure equilibrium with the testing atmosphere has been reached before any measurements are undertaken.

4.2.2. Apparatus Leakage Test & Measurement Integrity Check

A dummy standard shall be installed in the holder and a leakage test shall be performed to test the integrity of the measurement system.

(**Note:** A suitable dummy standard consists of a Pressure Drop transfer standard or a smooth metal tube of similar dimension).

The leak check shall precede any calibration or series of calibrations and shall be performed once on each day that calibration takes place.

4.2.2.1. Procedure for vacuum driven systems:

a. A dummy standard shall be installed in the calibration holder with its downstream exit end connected to the VFMD and its upstream end free to atmosphere.

b. The system shall be operated by application of a vacuum to the outlet port of the VFMD to create a negative pressure underneath the piston and at the exit end of the standard.

c. When the piston reaches the middle of the VFMD the dummy standard shall have its atmospheric end capped and the outlet port of the Vol-U-Meter shall be vented to atmosphere

d. After allowing sufficient time for the VFMD piston to become stationary (minimum 30 seconds), any leakage will be observed by monitoring the position and stability of the piston for a period of time to detect any leaks greater than 1,5 ml per minute.

e. The monitoring time (MT) for 1 mm movement of the piston required may be calculated using the following formula:

MT = (Cross Section Area (cm^2) * 0,1 cm) / 1,5 (ml/min)

(**Note:** For example for a VFMD, having nominal cylinder diameter of 44,5 mm, a minimum monitoring time of 1 minute is required, during which time any movement of the piston level shall be less than 1 mm. For a VFMD having a nominal cylinder diameter of 76,2 mm the equivalent leakage detection time for a 1 mm displacement would be 3 minutes).

4.2.2.2. Procedure for piston driven systems:

a. A dummy standard shall be installed in the calibration holder with its downstream exit end connected to the VFMD and its upstream end sealed from atmosphere.

b. The VFMD system shall be set to a dead volume of 1000 ml ± 100 ml. A negative pressure in the range of 2,8 to 3,2 kPa shall be applied.

c. After allowing sufficient time for the pressure to reach a stable value, the leakage volume shall be measured and shall not exceed 1,5 ml/min.

4.2.2.3. Monitor Reference Standards

The calibration laboratory shall maintain a set of reference standards that are used as calibration monitors, which shall be measured each day that the calibration laboratory is conducting measurements. The set of reference standards shall consist of a minimum of two standards of different Pressure Drop level and which covers the range of Pressure Drop measurements to be carried out.

A log shall be maintained of the measured values of monitor reference standards together with the operator identity and all ambient conditions at the time of test.

(**Note:** ISO 8258 and ISO 7870 give graphical methods for monitoring long-term measurement process stability).

If the measurements of the monitor reference standards are within the normal declared limits of uncertainty then the calibration apparatus shall be deemed fit for use.

If the measurements of the monitor reference standards are outside of the normal declared limits of uncertainty then the apparatus should be checked for leaks or measurement errors or both.

The monitor reference standards shall be rechecked following any remedial work

4.3. Calibration Method

This method describes a measurement procedure that generates a pressure drop across the standard under test proportional to the nominal 17,5 ml s^{-1} flow traversing it.

4.3.1. Measurement air, drawn from atmosphere through the standard under test shall be drawn through the system for a minimum of 5 minutes prior to measurement to ensure thermal equilibrium.

4.3.2. The air temperature and relative humidity of the testing atmosphere within the draught screen enclosure, containing the standard under test, shall be measured together with atmospheric pressure and shall be recorded for application in the compensation formula.

4.3.3. A stabilised volumetric flow of (17,5 ± 0,3) ml s^{-1} shall be established through the VFMD and drawn through the standard under test.

4.3.4. The static differential pressure between the exit of the standard and atmosphere shall be monitored and recorded throughout the time of the stabilised volumetric flow measurement.

4.3.5. One reading of pressure is the average of at least three contiguous repeat measurements of the differential pressure, recorded during the elapsed time of the stabilised volumetric flow.

4.3.6. The compensation formula (Appendix 5) shall be applied to the pressure reading to normalise the calibrated value of the Pressure Drop transfer standard to standard ambient conditions of 22 °C; 60 % RH; 1013 mbar and a flow of 17,5 ml s^{-1}.

4.3.7. Steps 4.3.3 to 4.3.7 shall be repeated a further two times. The compensated pressure drop value of the Pressure Drop transfer standard shall be recorded as the mean of the three replicate values of normalised pressure drop.

4.3.8. The calibrated value of the standard, rounded to the nearest 10 Pa (1 mmWG), shall be recorded on an accompanying calibration certificate and may be inscribed on the Pressure Drop transfer standard. The Pressure Drop transfer standard shall be inscribed with a unique reference identification number.

4.4. Certification

Each standard shall be supplied with a certificate of calibration, which shall contain the following minimum information:

a product name and unique reference number
b date of test
c operator reference
d description of testing apparatus and traceable reference serial numbers of all measurement equipment
e temperature of testing atmosphere in degrees Celsius (ºC) during testing
f relative humidity in percentage (RH %) during testing
g atmospheric pressure in hectopascals (hPa) during testing
h compensated pressure drop calibration value

i the calculated degree of non-linarity of the standard *

j limits of uncertainty of measurement.

k any observation during time of testing

* see appendix 5

4.5. Precision and Accuracy

During the development of this calibration method, an inter-laboratory trial was made between the suppliers of calibration standards. Four sets of Pressure Drop Transfer Standards were used in this study, each consisting of 4 standards, one each of nominal value 200, 400, 600 and 800 mmWG respectively. Each laboratory measured each set of standards using the method described in this appendix, all measurements on one set of standards being completed in one day. The measurements were then repeated on three other days to give a total of 4 days measurements.

This gave the following results: -

Nominal PD mmWG	Reproducibility Standard Deviation mmWG	Repeatability Standard Deviation mmWG
200	0,43	0,21
400	0,96	0,33
600	1,18	0,44
800	1,83	0,48

Notes:

1. The above inter-laboratory trial involved only three laboratories, there being only three competent laboratories known at present. Thus, the reproducibility and repeatability standard deviations are quoted rather than the r & R figures since the trial did not meet all of the criteria laid down in ISO 5257 for the assessment of measurement methods. This should be taken into account when comparing these figures with those for other methods.

2. To ensure that the practised methods and procedures do not suffer drift from the norm, it is recommended that calibration laboratories take part in annual collaborative studies. To this end, the above figures, and those obtained from future studies may be used to assess laboratory competence.

APPENDIX 3

REPEATABILITY AND REPRODUCIBILITY OF THE TEST METHOD

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

To determine the repeatability (r) and the reproducibility (R) of the test method an international collaborative study was carried out in 1994. The study involved 21 laboratories which tested 6 different types (levels) of cigarettes and 6 different types (levels) of filter rods.

Procedures and results are described below:

Selection of samples

The cigarette samples used in this study were supplied to the participants by different cigarette manufacturers. Some samples were taken straight from production without any special pre-selection, some were selected for total weight and one sample was selected for weight and pressure drop.

The values obtained for repeatability and reproducibility will in the case of cigarettes therefore not only reflect the variability in the measuring procedure but also the variability of the product.

The filter rod samples were all carefully selected for pressure drop. Each individual specimen was only allowed to differ by a maximum of ± 1,5% from the total mean value for each level.

The results for repeatability and reproducibility will therefore mainly reflect the variability of the measuring procedure.

Testing Procedures

- Before measuring, the samples were conditioned for at least 24 hours under the conditions of 22°C ± 2°C and (60% ± 5%) RH.
- For each measurement, 30 readings were taken, *i.e.* 30 randomly selected specimen were tested. A repetition of the test using 30 different specimens from the same sample was carried out after a short period of time, in all cases this happened on the same day.
- The individual samples could have been tested on different days, most laboratories carried out the testing on the same day.

Conditioning of the samples

As mentioned above, the laboratories were asked to condition the samples at 22°C ± 2°C and (60% ± 5%) RH for at least 24 hours before measuring. This is certainly not production floor practice but is has been found necessary to reduce the variation of the samples.

The actual conditions reported by the laboratories ranged from 21°C to 23,5°C and 59% RH to 66% RH for cigarettes. Only one laboratory exceeded the maximum value for moisture slightly, but not to an extent that the results of this laboratory were affected in any way.

For filter rods the conditions ranged from 20°C to 23.5°C and 57% RH to 63% RH.

Conditions during measurements

No specific requirements were made in the testing protocol for the ambient conditions during the measurement of the samples.

The actual conditions observed and reported were as follows:

	Temperature	Humidity	Atm. Pressure
Cigarettes	21.5°C – 26,5°C	42% RH - 64% RH	847 mbar - 1019 mbar
Filter rods	21.5°C – 24,5°C	42,5% RH - 64% RH	847 mbar - 1025 mbar

The atmospheric pressures correspond approx. to locations from sea level to 1800 metres (5900 ft.) above sea level.

Repeatability and reproducibility for the testing of cigarettes

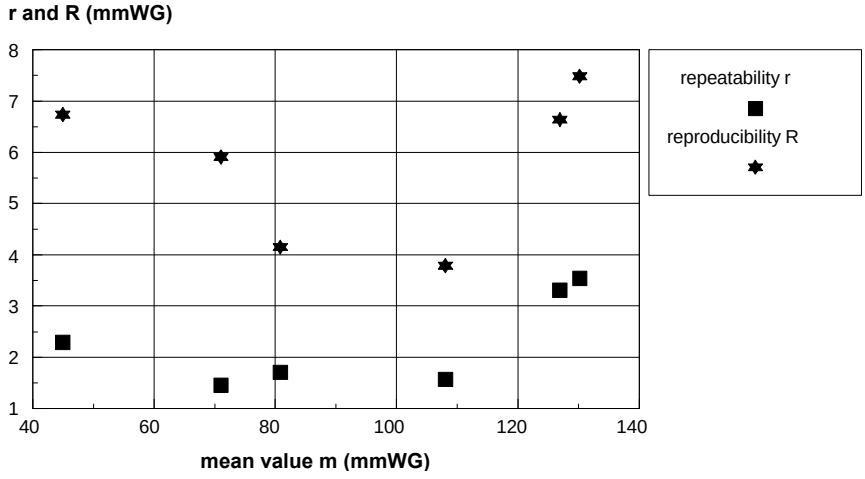
The values for m (mean pressure drop), r (repeatability), and R (reproducibility) are given (in mmWG) in the following table.

They were calculated as described in ISO 5725, page 18, section 14.7.

Computed values of m, r and R						
level	p	m	s_r^2	r	s_R^2	R
1	19	44,95	0,6695	2,29	5,8007	6,74
2	17	71,03	0,2697	1,45	4,4611	5,91
3	17	80,82	0,3712	1,71	2,1949	4,15
4	18	108,04	0,3139	1,57	1,8333	3,79
5	19	126,92	1,3939	3,31	5,6243	6,64
6	19	130,21	1,5997	3,54	7,1580	7,49

(p represents the number of participating laboratories)

Dependence of r and R on m (for cigarettes)



The figure shows that there is no evident correlation between the values for r and R and the mean levels m.

The final values for r and R were therefore determined as:

r = 2,3 mmWG

R = 5,8 mmWG

These values are valid for a pressure drop range of 40 mmWG to 130 mmWG.

Repeatability and reproducibility for the testing of filter rods

The values for m (mean pressure drop), r (repeatability) and R (reproducibility) are given in the following table.

They are calculated as described in ISO 5725, page 18, section 14.7

Computed values of m, r and R						
level	p	m	s_r^2	r	s_R^2	R
1	20	200,47	0,1885	1,22	2,7357	4,63
2	20	303,38	0,5727	2,12	5,8522	6,77
3	20	409,87	1,1458	3,00	11,1690	9,36
4	20	520,64	2,9353	4,80	19,2647	12,29
5	20	606,30	2,7427	4,64	24,8886	13,97
6	20	715,30	2,4642	4,40	32,9338	16,07

(p represents the number of participating laboratories)

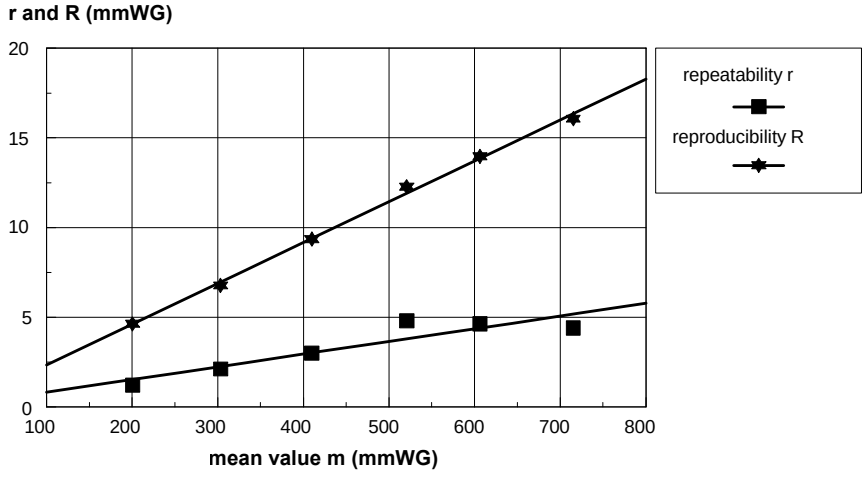
From the table above it seems clear that both r and R tend to increase linearly with higher values of m.

The figure below confirms this linear dependence. The dependence can be expressed by a straight line through the origin.

$r = b(r) \times m$

$R = b(R) \times m$

Dependence of r and R on m (for filter rods)



The final values of r and R can be expressed as linear equations.

The slopes of these lines, calculated as described in ISO 5725, page 24, chapter 15.6, are:

$r = 0{,}0072 \times m$

$R = 0{,}023 \times m$

m : mean value of pressure drop in mmWG

These values are valid for a pressure drop range of 200 mmWG to 700 mmWG.

APPENDIX 4

COMPARISON OF DRAW RESISTANCE MEASUREMENT CRITICAL FLOW ORIFICE INSTRUMENTS VS. CONSTANT MASS FLOW INSTRUMENTS

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

Due to different interpretations of ISO 6565:2002, there are currently two types of instruments used for the measurement of draw resistance (or pressure drop). The two instruments described below both operate under vacuum.

The first type operates with a critical flow orifice (CFO) which is a constant volumetric flow device. These instruments maintain a constant volume of air at the exit of the test piece regardless of the pressure; the flow rate at the inlet end will fall with increasing pressure drop of the test piece. Thus, the mass flow through the test piece will be lower as the pressure drop of the test piece increases.

The second type operates with a constant mass flow device (CMF) which maintains a constant mass flow of air through all test pieces. These instruments maintain a constant mass flow of air by automatically compensating for changes in pressure at the exit of the test pieces. As a result the volumetric air flow at the inlet to the test piece remains constant. Since the flow rate through a CMF is always greater than the flow through a CFO on the same test piece, the pressure drop readings obtained with a CMF are higher than with a CFO device.

This recommended method requires the use of instruments which maintain a constant volumetric flow at the exit of the test piece, *e.g.* instruments with a CFO device.

The relationship between the pressure drop readings obtained with a CFO device or with a CMF device can be expressed by the following equations:

$$PD_{CMF} = PD_{CFO} \frac{P_A}{P_A - PD_{CFO}}$$

$$PD_{CFO} = PD_{CMF} \frac{P_A}{P_A - PD_{CMF}}$$

where:

PD_{CFO} pressure drop observed with a CFO device

PD_{CMF} pressure drop observed with a CMF device

P_A atmospheric (ambient) pressure

Examples:

$PD_{CMF\ (mmWG)}$	$PD_{CFO\ (mmWG)}$	$PD_{CFO\ (mmWG)}$	$PD_{CMF\ (mmWG)}$
100	99	100	101
150	148	150	152
200	196	200	204
300	291	300	309
400	385	400	416
500	476	500	526
600	566	600	638
700	655	700	752
800	741	800	869

As can be seen, the practical differences are basically insignificant for pressure drop values below 200 mmWG but become increasingly significant for values above 300 mmWG.

APPENDIX 5

DESCRIPTION OF THE COMPENSATION PROCESS

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

The compensation process is described in detail in the paper "Compensation for the effects of ambient conditions on the calibration of multi-capillary pressure drop standards", S. Colard, W. Trinkies, G. Cholet, B. Camm, M. Austin and R. Gualandris, Beiträge zur. Tabakforschung International 21/3 (2004) 167-174 (www.beitraege-bti.de). This compensation has been validated for the most commonly used pressure drop standards composed of ten parallel capillary tubes, the structure being made of glass. A short description of the compensation process is given below.

Pressure drop (PD) values are influenced by the ambient conditions during calibration, i.e. by temperature T and relative humidity RH of air, and atmospheric pressure P. One way of reducing the influence of these ambient factors is to apply compensation. A suitable compensation formula can be derived by considering the effects of ambient conditions on the basic characteristics of the measurement air. When calibrating PD standards, the objective of the compensation formula is the calculation of a pressure drop value, PD_S, at standard ambient conditions (T_S = 22°C, RH_S = 60%, P_S = 1013 hPa, Outlet airflow Q_S = 17.5ml/s) from PD measurements, undertaken at different conditions (T, RH, P, Q).

PD can be approximated to a sum of two values PD_1 and PD_2, PD_1 being characteristic of the non linear behaviour of the standard and PD_2 of the linear behaviour.

A degree of non-linearity x can then be defined such as:

$$\begin{aligned} PD_1 &= x \times PD \\ PD_2 &= (1-x) \times PD \end{aligned} \qquad (1)$$

The value of x has been experimentally determined over the PD range [200-800mmWG]:

$$x = 3,41 \times 10^{-5} \times PD + 3,38 \times 10^{-2} \qquad (2)$$

It can be shown that the compensated PD value can be derived from the two following equations where PD_{1S} and PD_{2S} are the unknown parameters:

$$PD_{2S}^2 - (P_S - PD_{1S}) \times PD_{2S} + \frac{\eta_S \times T_S}{\eta \times T} \times (P - PD) \times PD_2 = 0 \qquad (3)$$

$$PD_{1S}^3 - 2 \times P_S \times PD_{1S}^2 + P_S^2 \times PD_{1S} - \frac{\rho_S \times T_S^2}{\rho \times T^2} \times PD_1 \times (P - PD_1)^2 = 0 \qquad (4)$$

with PD_{1S} and PD_{2S} : the compensated values of PD_1 and PD_2, in mmWG.

η and ρ : air viscosity and density respectively during the calibration

η_s and ρ_s: air viscosity and density respectively at the standard ambient conditions

T and T_s expressed in Kelvin

P and P_s expressed in mmWG

After resolving these equations, the standard *PD* value with an outlet volumetric airflow of 17,5 ml s^{-1} can be then approximated by:

$$PD_{S,17,5ml/s} \cong PD_{1S} \times \left(\frac{17.5}{Q(P_S, T_S, PD_S)} \right)^2 + PD_{2S} \times \left(\frac{17.5}{Q(P_S, T_S, PD_S)} \right) \qquad (5)$$

with Q expressed in ml/s

Numerical example of compensation:

During calibration of a standard, the following parameters were measured:

- PD = 389,3 mmWG
- Q = 17,65 ml/s
- T = 22,7 °C (295,9 K)
- P = 1015,3 hPa (10356 mmWG)
- RH = 56,1 %

The corresponding air density and viscosity are:

- η = 1,825×10^{-5} Pa.s
- ρ = 1,188 kg/m^3

The equation (2) gives an assessment of the degree of non-linearity x:

x = 4,71 %

PD_1 and PD_2 can then be calculated with equation (1).

Solving equation (4), PD_{1S} is obtained:

PD_{1S} = 18,3 mmWG

Then, equation (3) allows the determination of PD_{2S}:

PD_{2S} = 370,2 mmWG

The perfect gas law is used to calculate $Q(P_s, T_s, PD_s)$:

$Q(P_s, T_s, PD_s)$ = 17,65 ml/s

And finally, using the equation (5), PD_s is normalized to 17,5 ml s^{-1}, which gives:

$PD_{s,17,5ml/s}$ = 385,2 mmWG

From this compensated value, the degree of non-linearity can be adjusted more accurately:

x = 4,69 %

The new solutions of the equations (3) and (4) are then calculated a last time. In this case, the final compensated value remains as $PD_{s,17,5ml/s}$ = 385,2 mmWG