



**Cooperation Centre for Scientific Research
Relative to Tobacco**

CORESTA Guide N° 14

**A User Guide for the Determination
of the Diffusion Capacity (D^*)
of Cigarette Papers**

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Physical Test Methods Sub-Group



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Table of Contents

1. INTRODUCTION.....	4
1.1 Background to diffusion capacity (D^*) measurements	4
1.2 Rationale for developing this CORESTA Guide.....	4
2. THE DIFFUSION CAPACITY MEASUREMENT PROCESS	4
2.1 Principle of measurement	4
2.2 Definitions	5
2.3 Compensation for dilution of diffusing gases.....	6
2.4 Measurement systems	7
2.5 Factors affecting the measured diffusion capacity	7
3. CONFIRMING CORRECT INSTRUMENT FUNCTION	8
3.1 Introduction.....	8
3.2 Routine measurement of a test piece or test samples.....	9
3.3 Methods of checking and assuring instrument function	9
4. CHECKING THE VALIDITY OF MEASUREMENTS	9
4.1 The validation process	10
4.1.1 The purpose of measurement consistency checking.....	10
4.1.2 Precautions during measurement checking.....	10
4.1.3 A recommended process for measurement consistency checking.....	11
4.2 Checking instrument performance.....	11
4.2.1 Measuring repeatability	11
4.2.2 Measuring reproducibility.....	12
4.2.3 Instrument-to-instrument variability	12
5. MAKING DIFFUSION CAPACITY DETERMINATIONS	13
5.1 Sample preparation and handling	13
6. POTENTIAL IMPROVEMENTS OF THE MEASUREMENT PROCESS	14
6.1 Use of humid gases	14
6.2 Measurement at a defined pressure.....	14
6.3 Development of a reference method.....	15
6.4 Development of a reference material.....	15
7. GLOSSARY AND ABBREVIATIONS.....	16
8. REFERENCES.....	17

1. INTRODUCTION

1.1 Background to diffusion capacity (D*) measurements

The determination of diffusion capacity D^* (D-star), particularly for banded Lower Ignition Propensity (LIP) cigarette papers, is a technique that has increased in importance with the development of cigarettes to meet the pass criterion^[1] set for the assessment of ignition propensity^[2,3]. Diffusion capacity, which has often been referred to more loosely as ‘diffusivity’, is an additional characteristic of cigarette papers and is likely to exist alongside the long-established measurement of air permeability.

The CORESTA Recommended Method N°40 for air permeability measurement was published in 1994 and converted to ISO Standard 2965 in 1997, revised in 2019^[4]. The standard acknowledges that permeability measurements would be made on the banded papers widely used in the construction of LIP cigarettes. Air permeability is measured under a differential pressure of 1 kPa, whereas the measurement of diffusion capacity is based on the transfer of a marker gas through the paper under essentially zero differential pressure.

Studies^[5,6,7] have shown that the transfer rate through the paper of oxygen, carbon monoxide and carbon dioxide under minimal differential pressure, i.e. the diffusion capacity, has a significant influence on the smouldering behaviour of cigarettes. Studies^[8] of the correlation between air permeability, diffusion capacity and pass/fail performance in the ISO 12863:2010 or ASTM-E2187-09 tests for ignition propensity have demonstrated that diffusion capacity, particularly of the low-diffusivity bands, provides a better correlation to test performance than does permeability. Therefore diffusion capacity is being increasingly adopted as a key material specification for banded papers used in the construction of LIP (Fire Standard Compliant, FSC) cigarettes.

1.2 Rationale for developing this CORESTA Guide

This CORESTA Guide is intended as a reference for the manufacturers of cigarette papers and cigarettes as to the best practice for the measurement of diffusion capacity of cigarette papers, so as to consistently obtain the most accurate and reliable measurements. It supports the CORESTA Recommended Method relating to Diffusion Capacity Measurement, CRM N°77^[9].

2. THE DIFFUSION CAPACITY MEASUREMENT PROCESS

2.1 Principle of measurement

A test piece (usually cigarette paper) is held in a measurement head (paper clamp) and divides the head into two equally dimensioned chambers. An equivalent constant volume flow of different gases is introduced to flow in the same direction across the paper within each chamber. Gas is exchanged between the chambers by diffusion through the paper. Conventionally the diffusion process is monitored by the diffusion of carbon dioxide (CO₂) in a nitrogen (N₂) carrier although the work that established the principles of the method^[10] used carbon monoxide (CO) as the measured diffusing gas. The steady-state volume flow rate of CO₂ diffusing through the test piece into N₂ can be determined from the gas flow rate and the concentration of CO₂ in the outflow gas. This applies equally whether the CO₂ is delivered to one side of the paper either as pure CO₂ or as CO₂ of known concentration carried in N₂.

The principle of measurement is illustrated in Figure 1, referring just to the transferred CO₂.

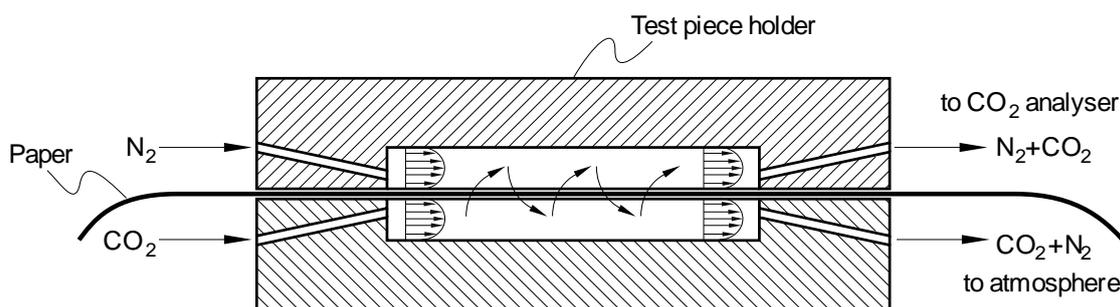


Figure 1. Simplified diagram of gas exchange in the measurement head

The sample is placed in the test piece holder so that CO₂ will be transferred from the side facing the tobacco to the outside as it would occur on the finished product, e.g. a cigarette, where this is known, i.e. the CO₂ chamber faces the printed/banded side of the cigarette paper.

2.2 Definitions

CO₂ Diffusion Capacity: Unit of measurement

The Diffusion Capacity of the paper is the volume flow rate of gas present on one side of the paper into gas on the other side through cigarette paper in cm³·s⁻¹ per cm² of clamp area, (cm³·s⁻¹)·cm⁻². Conventionally this is simplified and expressed as the flow velocity in cm·s⁻¹. This unit is referred to in the industry as **D*** (D-star). In practice, diffusion capacity is determined by following the diffusion of CO₂ into N₂. For information, typical diffusion capacity values for current generation papers (in 2012) are:

- Band regions: 0,02 cm·s⁻¹ – 0,25 cm·s⁻¹
- Base paper regions: 1,0 cm·s⁻¹ – 2,5 cm·s⁻¹

These values may change as the technology develops.

NOTE: The unit for D* is analogous to the CORESTA unit of air permeability that is expressed as volumetric flow rate per minute per unit area under a differential pressure of 1 kPa, which has units of (cm³·min⁻¹)·cm⁻² or cm·min⁻¹.

‘Diffusivity’ and ‘Diffusion Capacity’

Diffusivity is the proportionality constant between the molar flux passing through a plane in a material due to molecular diffusion and the concentration gradient (or the driving force for diffusion). Diffusivity has units of area per time; cm²·s⁻¹ in the context of this document^[a]. Norman & Henderson, in their description of a practical apparatus to measure gas diffusion^[11], pointed out that this is not a useful definition for a cigarette paper, since to be useful the thickness of the paper would also have to be known. They thus defined the Diffusion Capacity (D*) as a more directly applicable measure of the actual sample under test, not to the material of which it is made. Thus a thicker sample of the same material, with the same diffusivity, would be expected to deliver a lower diffusion capacity value. D* has units of (cm³·s⁻¹)·cm⁻² = cm·s⁻¹.

^[a] The units of diffusivity are best understood as, ('amount of substance' [mol] per area per time) per (concentration gradient) [mol·length⁻³·length]. Thus, Units of Diffusivity constant = mol·length⁻²·time⁻¹·mol⁻¹·length³·length = length²·time⁻¹

Initially, the rather fine distinction between ‘diffusivity’ and ‘diffusion capacity’ was perhaps not fully appreciated, so that diffusivity became the common term describing gas flow through paper; for example instruments tend to be referred to as Diffusivity Testers (or equivalent). However, measurements have always been presented as the diffusion capacity of the measured paper sample. This CORESTA Guide uses ‘Diffusivity’ as a generic term relating to the diffusion process and to describe *materials* (e.g. low diffusivity bands and high diffusivity base papers) and always uses ‘Diffusion Capacity’ or D^* when referring to the resultant measurements.

Measurement region

The measurement head contains an active region that is small enough to measure either low diffusivity bands, which, at the time of writing, are typically 5 mm - 7 mm wide or the original base paper regions, which are typically 18 mm - 22 mm wide. Current generation instruments feature a measurement area that is 2 mm - 4 mm wide by 10 mm - 20 mm in length - this is normally oriented across the paper, as illustrated in Figure 2.

Position of measurement area

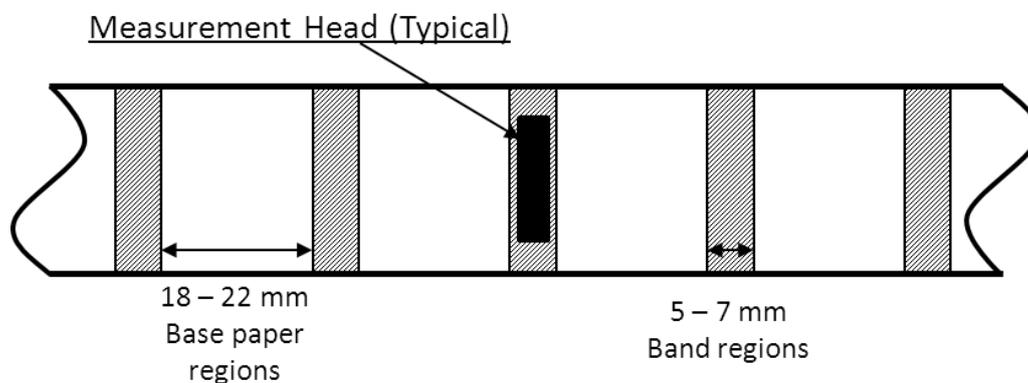


Figure 2. Schematic illustration of banded LIP Paper with the measurement head positioned to determine band diffusion capacity

Differential pressure

A significant aspect of the measurement of diffusion capacity is that the transfer of gas through the paper must not be significantly affected by an imposed differential pressure. Differential pressure is minimised in instruments by balancing the flow rate and impedances in the flow paths on either side of the paper. There is potentially a small pressure differential introduced by unbalanced diffusion through the paper. Practical experience at the time of writing suggests that the pressure differential should be less than 10 Pa (~1 mmWG) so as not to significantly affect the measurement. Current instrumentation displays and/or records the actual pressure differential experienced during measurement.

Conditions for paper conditioning and testing

The standard conditions for Paper Conditioning and Testing are defined in CRM N° 77.

2.3 Compensation for dilution of diffusing gases

Referring to Figure 1 it can be seen that the gases delivered to the paper at the inlet to the diffusion cell on the left of the diagram are diluted by gas diffusing through from the other side of the paper as they flow towards the outlet on the right. Thus a measurement of CO₂ content of the outlet gas does not lead directly to a simple calculation for diffusion capacity - it is always an underestimate. The crucial factor is the concentration of CO₂ along the two opposite faces of the paper since this determines the concentration gradient through the paper that drives diffusion.

This concentration is itself a function of:

- the gas flow rate
- the D^* value of the paper
- the chamber dimensions
- the diffusion of CO_2 towards and away from the paper surfaces within the gas flow paths.

A further complication is that the gas flow along the channels exhibits a velocity gradient, with the gas flowing fastest along the centre of the channels and more slowly towards the paper and clamp surfaces. Drake et al^[10] developed an analytical solution to model the diffusion and flow situation that required some significant simplifying assumptions and also adopted an iterative solution method to derive the D^* value from measurements of flow rates and the concentration of the transferred gas. Norman^[11] fitted a polynomial expression to Drake's solution to simplify the D^* calculation for a fixed flow geometry and gas flow rate. More recently, the situation was analysed using numerical 3D modelling^[12] that removed the need to adopt some (but not all) of the simplifying assumptions.

At the time of writing, a model has not yet been developed to calculate D^* from the raw measurements that is free from significant assumptions concerning this complex diffusion and flow situation.

2.4 Measurement systems

Currently available diffusivity testers use the measurement principle illustrated in Figure 1.

The two gases are delivered to the measurement head and pass over the paper at equal flow rates. This is achieved and metered either by a pair of mass-flow controllers or by exhausting pre-filled calibrated syringes of each gas. After passing over the paper, the gas to be analysed is vented through a CO_2 meter that is either in-line to the downstream N_2 flow or that is fed from a vacuum ejector drawing gas from the downstream N_2 flow. The net volume flow rate of CO_2 that has diffused through the paper can be determined as the volume flow rate of initially pure N_2 multiplied by its CO_2 concentration after it has passed over the paper.

The measured CO_2 concentration is converted to the D^* value. This includes extraction of the dilution effect of cross-diffusion discussed in section 2.3. It should be noted that different instrument types adopt different terminology for their internal measurements so only the converted D^* measurement, which is also compensated to standard measurement conditions, should be used as the basis of comparison.

2.5 Factors affecting the measured diffusion capacity

The measured diffusion capacity is affected by the following factors:

- Temperature, humidity and duration of the pre-conditioning period of the sample to be tested
- Time delay between removing the sample from the conditioning environment and measuring (if different)
- Evolution / stability of the measured value during the measurement process
- Temperature, humidity and atmospheric pressure at the time of measurement
- Sample handling and preparation
 - see section 5

- Physical condition of the sample
 - see section 5
- Incorrect / out-of-tolerance instrument set-up, such as:
 - excessive pressure difference across the paper at the time of measurement
 - volume flow of test gases
 - absolute pressure within the measurement chambers
 - accuracy of the measurement of gas flow during measurement
 - calibration of gas flow
 - chamber dimensions
 - leakage (exchange with air) that influences the measured gas composition
- Accuracy of the measurement of CO₂ concentration of the analysed gas
 - calibration of the CO₂ sensor (zero, span and linearity)
- Content, temperature and purity of gas supplies for measurement and calibration
 - CO₂ and N₂ should be of the following minimum purity:
 - CO₂: 4.5 (99,995 %) - where a CO₂ / N₂ mix is used as the CO₂ source then the closest available grade should be used
 - N₂: 4.0 (99,99 %)
 - calibration gas should be of the following minimum quality:
 - relative analytical uncertainty of better than ±1 % of the certified value

Diffusivity and thus also diffusion capacity depend substantially on temperature and pressure at which the diffusion process takes place. Current diffusivity testers work at ambient temperature and at approximately ambient pressure in the measurement chamber. In order to be able to compare diffusion capacity values obtained at different ambient conditions, it is necessary to convert diffusion capacity values to the same ambient conditions. Examples of a procedure for converting diffusion capacity values to standardized ambient conditions are described in Annex A.1 of CRM N° 77^[9] and in a separate study^[13].

In general, the expression and interpretation of measurement results requires knowledge of the capability and uncertainty of the measurement process to ensure that valid inferences are drawn from the results.

3. CONFIRMING CORRECT INSTRUMENT FUNCTION

3.1 Introduction

Checks for diffusivity tester function are performed in order to ensure that all instrument components and systems are set up and operating correctly. They are separate from any measures of instrument performance and are a necessary pre-condition for all of the following checks and validations.

3.2 Routine measurement of a test piece or test samples

Routine checking of a test piece, which is re-measured many times in the same position, or test samples, where the measurement position is changed each time, are widely practised ways of checking instrument function as a whole. Thus measurements are made on samples with known measured values and the history of measurements is documented, commonly as a control chart. Over time the variability of the method and sample is established so that measurements that fall outside the expected range can be identified. When such a measurement is taken, appropriate action can be taken to check that the instrument is functioning correctly and any required remedial action can follow.

3.3 Methods of checking and assuring instrument function

The first step in assuring correct function should be a programme of regular preventative maintenance. Instrument manufacturers provide information and guidance on instrument maintenance and offer programmes of planned maintenance. These should include attention on a regular basis (e.g. daily, weekly and annually). Differences between instruments from different manufactures mean that there will be some differences in their recommended maintenance programmes. However, routine tasks, which may vary in frequency from daily to (several) monthly should include:

- Routine measurements on test piece or test samples (as discussed above).
- Routine measurement for accuracy of gas flows and CO₂ analyser to ensure no sporadic or systematic drifts.
- Checks on instrument supplies.
 - Check that all gases and vacuum / inlet pressures are set correctly.
- Check the integrity of the measurement head (for potential sources of leaks).
- Checks for build-up of contamination within the instrument.
 - Periodically remove all paper dust from the measurement head and gas flow paths.
- A test measurement to confirm correct operation following any maintenance or adjustment.

Planned maintenance should be supplemented by regular functional checks to provide early warning of faults. Alternatively, critical observation of key instrument functions under normal operating conditions of use can show up developing faults. Such observation can usefully be carried out as part of a test measurement run following routine preventative maintenance.

4. CHECKING THE VALIDITY OF MEASUREMENTS

The process to check the validity of measurements normally comprises the following stages:

- Functional check of instrument performance
- The calibration process, comprising:
 - Checking against a transfer standard / reference product
 - Adjustment if required
 - Verification of calibration process

A significant issue that currently affects calibration checking of diffusivity instruments is that there is neither a standard method nor a physical standard available for checking the calibration or calibration accuracy. Thus it is not possible to link an instrumental measurement via a certified standard to an accepted reference value. As noted in section 3.2, a test piece or test samples are available as recommended by instrument manufacturers. Alternatively paper samples can be identified and repeatedly measured to act as the test sample. It is therefore more appropriate to consider this a measurement validation procedure.

At the time of writing calibration of diffusivity instruments comprises calibration of the flow control and gas analysis functions. It does not comprise a direct calibration of diffusion capacity based on the known and accepted value of a transfer standard.

4.1 The validation process

4.1.1 The purpose of measurement consistency checking

Measurement consistency checking is an essential part of the overall verification and calibration process and is done to confirm whether the instrument is measuring within the required and/or expected limits of accuracy, as assessed using a control chart^[8]. A check should be carried out at regular intervals and frequently enough to detect changes in instrument measurements due to, for example:

- The effects of measurement system drift.
- The effects of changes in ambient conditions.

As a minimum, it is recommended that a check is carried out every manufacturing period or shift and at least once per day.

If a check shows that an instrument is measuring outside the required limits then it shall be investigated and potentially recalibrated and adjusted.

4.1.2 Precautions during measurement checking

A measurement consistency check of an instrument can be made by measuring a test piece or test sample in the instrument. The measured value will indicate how closely the instrument is measuring to the expected value. A decision can then be made as to whether to recalibrate the instrument or not.

When carrying out such a check it is necessary to ensure that the measured value is valid. This will avoid unnecessary readjustment. In particular:

- Ensure that the instrument is placed in a stable environment, as specified in CRM N° 77.
- Allow sufficient warm-up and settling time after switching on, following the recommendations of the instrument manufacturer.
- The test piece or sample should be in equilibrium with the measurement environment.
- Include a check for non-linearity within the measurement device.

NOTE: This can be most easily achieved by checking with different values of test piece or reference sample covering the measurement range. Any non-linearity indicates a possible problem with the unit or possibly with a test piece. Confirm the error using additional test piece/sample(s) and rectify it before proceeding.

4.1.3 A recommended process for measurement consistency checking

To carry out a measurement consistency check, proceed as follows:

- Referring to the manufacturer's instructions, place the instrument into the appropriate mode.
- Insert the test piece/sample into the instrument measurement head.
- Observe the measured value and record the value.
- Compare the measured value with its expected value:
 - If the measured value differs from the expected value by more than a pre-defined allowable limit, then this should be investigated and potentially the instrument should be recalibrated.
 - If the measured value is within the allowable limit then the instrument does not require recalibration.

NOTE: The allowable limits should be set by reference to the uncertainty of the measurement repeatability and the capability of the measurement process. This is most easily determined by regular use of a Shewhart Chart to plot the measured values for the calibration standards^[14, 15].

4.2 Checking instrument performance

This is a means of assessing the dynamic measurement performance of an instrument. It is not necessary to carry out this step for routine verification and calibration checking but it should be carried out periodically and particularly after any significant service work or repairs to the instrument.

The purpose of this check is to confirm:

- That the instrument is functioning and operating correctly.
- That the instrument is adjusted correctly for the product being measured and is capable of measuring the product correctly.
- The measurement capability of the instrument, which may then be used to assess the measurement repeatability and reproducibility.

NOTE These values allow an assessment of the allowable limits for validation checking. An instrument cannot be more accurate or precise than its uncertainty of measurement.

4.2.1 Measuring repeatability

Repeatability represents a measure of the closeness of agreement (precision) between independent measurements, made on one instrument, by one operator and within a short period of time^[16]. Repeatability is normally tested by measuring a series of samples twice in quick succession on one instrument without any re-calibration of the instrument.

The samples used should be stable and should closely represent the actual samples normally measured on the instrument. The samples should be selected to have minimal intra-sample variability to reduce the sample contribution to measurement variability. Depending upon the type of instrument being tested, examples of suitable samples are:

- Cigarette papers including banded LIP papers
- Tipping base papers
- Laser-drilled metal test piece (multi valued)

- Impermeable material (plastic or rubber strip)
- Filter materials with tightly controlled pore density and diameter
- Card (thick paper)

Precautions should be taken to avoid sample degradation from measurement to measurement. Dependent upon the type of sample, these include:

- Minimising the amount of handling of the samples.
- Avoiding repeat measurement over the same area in materials that can be influenced by the clamping process (including any material included in the clamped area) or by drying of the measured zone by the two operating gases so that the measured value is not consistent.
- Preparing or cleaning a repeatedly measured test piece.

To obtain a truly representative figure, the repeatability test should be carried out in the same location in which the instrument is normally used. This figure will then include any environmental effects that are present.

NOTE: Before carrying out any testing of repeatability or reproducibility, users should ensure that the instruments concerned have been properly calibrated and validated, as described in section 4.1.

4.2.2 Measuring reproducibility

Tests of reproducibility are a means of assessing the maximum difference to be expected between the measured values of a sample when measured in different laboratories and by different operators. For diffusion capacity (D^*) measurements, this can be influenced by many factors, including:

- Instrument repeatability
- Differences between the methods used to calibrate each instrument
- Uncertainty in the calibration gas composition used for span calibration of the CO₂ sensor
- Local differences in operator procedure and technique
- Sample preparation and handling
 - see section 5.1

4.2.3 Instrument-to-instrument variability

Instrument-to-instrument variability testing is carried out in a similar way to repeatability testing, except that the two measurements are made on different instruments and may be carried out over an extended period of time.

In addition, there may be several measurement runs, each on a different instrument. This allows testing across a population of instruments within an organisation and allows comparison between any one instrument and the mean of all the instruments. This can be used to determine any bias between the instruments.

Samples for instrument-to-instrument variability testing can be the same as those for repeatability testing.

NOTE: The actual instrument-to-instrument variability cannot be better than the repeatability of the individual instruments and will also include any differences between the methods used to calibrate each instrument. These values will also depend upon local conditions.

5. MAKING DIFFUSION CAPACITY DETERMINATIONS

The exact procedure for determining the diffusion capacity of paper samples will depend not only on the type of sample to be measured but also on the type of instrument used. There are a number of points, however, that need to be checked for all diffusion capacity measurements:

- The instrument (for example measuring head dimension, measuring range) used should be suitable for the type of product to be measured.
- Samples should be conditioned prior to measurement according to section 2.2.
- Samples should be handled carefully to avoid damage and changes of sample moisture and temperature.
- Validation checks should be made frequently enough to avoid errors in measurement due to changes in ambient conditions.

5.1 Sample preparation and handling

The following guidelines for handling of samples and for measurement of D^* shall be followed:

- For band identification, high contrast fluorescent marker (ideally pink or blue) should be used to trace a thin mark at the edge of the banded paper sample on the printed side. The position of the bands will be defined where the ink does not penetrate (or penetrates more faintly) to the other side of the paper. The mark should not overlap with the measured area. See Figure 3 for examples of bad and good practice.
- Positioning lines drawn on the measurement head are helpful to position the sample.
- Direct handling of bands with bare fingers must be avoided. Nitrile (powder-free) or cotton gloves can be used.
- All papers should be placed in the test piece holder so that the CO_2 will travel from the inner face towards the outer face of the paper as it is applied in the construction of the finished product, where this is known. This means banded side down on current generation instruments (band facing the CO_2 chamber), so that the band position is visible on the top side of the paper.
- Zones for measurement should be free of dust, wrinkles, holes or any other visible damage.
- A band shall only be measured once unless otherwise specified. If a band is misaligned, switch to the next untouched band.

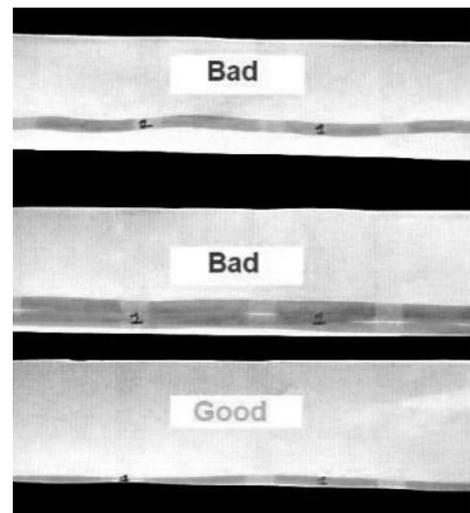


Figure 3. Examples of bad and good practice for band marking

6. POTENTIAL IMPROVEMENTS OF THE MEASUREMENT PROCESS

Although currently repeatability and reproducibility of the method described in CRM N° 77 satisfy industry needs, improvements of the measurement process are still possible. It may be expected that any technical changes to the method itself will affect the diffusion capacity values not only with respect to their variability but also with respect to their mean value. However, as mentioned above there are no reference method, reference standards or transfer standards for diffusion capacity available, which would allow a calibration of the measurement process as a whole and through adjustment a compensation of such changes. Therefore it may be difficult to establish a relationship between diffusion capacity values obtained before and after a technical change of the method, which might invalidate LIP cigarette paper specifications agreed between cigarette paper suppliers and cigarette manufacturers. For these practical reasons there is an interest to keep the measurement method as it was originally designed, even though from a scientific point of view improvements might be desirable.

Some options for potential improvement that have been identified shall be described below for any future technical revision of CRM N° 77.

6.1 Use of humid gases

The gases currently employed in the measurement of diffusion capacity are dry. Cigarette paper and to a certain extent also materials used in the LIP bands on the cigarette paper are strongly hygroscopic and will change their properties as they dry out during the measurement process. This may explain some of the changes observed in diffusion capacity during the measurement and makes it difficult to define termination criteria, i.e. the conditions when the measurement process shall be stopped and the diffusion capacity value accepted as the ‘correct’ value.

Also the diffusion capacity of the LIP bands on a cigarette paper determined by this method may not necessarily be representative of the diffusion capacity existing at the time a cigarette manufactured using this cigarette paper is subjected to ignition propensity testing.

Thus more stable and representative diffusion capacity values may be expected, if the gases used for the measurement contain a defined amount of water vapour, preferably an amount which corresponds to the 50 % RH used for conditioning of the cigarette paper samples.

6.2 Measurement at a defined pressure

The diffusion process in the measurement chamber takes place at approximately ambient pressure. This pressure varies substantially depending on weather conditions and altitude of the laboratory location. It thus affects not only reproducibility but also the stability of the measurement within a single laboratory.

While there is a calculation model described in CRM N°77 Annex A.1 for compensating the influence of pressure and temperature, this model is just theoretical and has not been validated using real diffusion capacity measurements. It may therefore be beneficial to modify the set-up of the measurement chamber such that the measurement takes place at a defined absolute pressure, which may be slightly higher than ambient air pressure, e.g. 120 kPa, but is then the same in all instruments and at all laboratory locations.

To a certain extent this also applies to the gas temperature, but, if the instrument is set up correctly, temperature can already be controlled in sufficiently tight limits.

6.3 Development of a reference method

A reference method that may assign a widely accepted diffusion capacity value to a reference material might be a further step towards improving reproducibility. Such a reference method could eliminate or reduce some influences that are currently believed to negatively affect the reproducibility of diffusion capacity measurement. For example, the measurement could take place in a chamber separated by the material to be tested into two compartments of equal dimensions but without any gas flow taking place in the compartments. As significant assumptions about the gas flow in the measurement chamber have been made to derive the calculation models for diffusion capacity, this source of uncertainty could be eliminated.

Furthermore, in agreement with the discussion above, defined pressure, temperature and relative humidity in the measurement chamber can further help to reduce variability.

6.4 Development of a reference material

It has become common in the industry to use certain cardboard sheets for monitoring the stability of individual diffusivity testers in a laboratory and also to match several diffusivity testers within a laboratory to each other by appropriate mathematical correction of diffusion capacity values. While these cardboard sheets have shown surprising stability over time, it might still be desirable to have a reference material with guaranteed availability, composition and properties available. So far, however, although several different options have been considered, such as laser-drilled metal sheets, filter materials, glass pieces, sintered metal pieces etc. no suitable reference material has been identified.

The main reason seems to be that the small pores present in cigarette paper cannot be manufactured artificially in any suitable sheet material. Further work may therefore be needed to find such a reference material, which in combination with a reference method, may allow a calibration of the measurement process as a whole and would substantially improve the agreement between different diffusivity testers.

7. GLOSSARY AND ABBREVIATIONS

ASTM	The American Society for Testing and Materials, today ASTM International
°C	Degrees Celsius
CEN	The European Committee for Standardization
CORESTA	Cooperation Centre for Scientific Research Relative to Tobacco
CRM	CORESTA Recommended Method
D* (D-star)	Industry unit for Diffusion Capacity, $\text{cm}\cdot\text{s}^{-1}$
Diffusivity	The proportionality constant between the molar flux due to atomic/molecular diffusion and the concentration gradient (or the driving force for diffusion). Diffusivity has units of $\text{cm}^2\cdot\text{s}^{-1}$ in the context of this document
FSC	Fire Standard Compliant or Fire Standard Compliance. FSC is used in the USA to denote cigarettes that meet the requirement for self-extinguishment measured using ASTM-E2187
ISO	International Standards Organisation
ISO TC 126	ISO technical committee for standardisation of terminology and test methods for unmanufactured tobacco, all types of tobacco products, materials used for manufacturing tobacco products and tobacco smoke including environmental tobacco smoke aspects
LIP (also RCIP)	Lower Ignition Propensity (Reduced Cigarette Ignition Propensity) LIP is the preferred CORESTA term relating to self-extinguishing cigarettes and materials used in their manufacture (e.g. LIP Papers)
%RH	Relative humidity
Shewhart Chart	A statistical tool in the form of a control chart intended to assess the nature of variation in a process

NOTE: ASTM E2187-09 and ISO12863:2010 as well as other related national standards are broadly equivalent tests used to determine the self-extinguishing characteristics of cigarettes when placed on a substrate.

8. REFERENCES

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