STANDARD REFERENCE METHODS FOR SOURCE TESTING: MEASUREMENT OF OPACITY OF EMISSIONS FROM STATIONARY SOURCES

Air Pollution Control Directorate
Environmental Protection Service

Report EPS 1-AP-75-2
November 1977

Cat. No.: EN 42-1/75-2

ISBN—0-662-01466-9

FOREWORD

The test methods (transmissometry and trained observer) presented in this report are used to determine the opacity of visible emissions from stationary sources.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 METHOD A - VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

1.1 Principle

The opacity of emissions from stationary sources is determined visually by a qualified observer.

1.2 Applicability

This method is used to determine the opacity of emissions from stationary sources and to qualify observers in the visual determination of emission opacity.

1.3 Range and Sensitivity

An observer qualified in accordance with the procedure in the Appendix is able to assign to plumes opacity readings from 0% to 100% in 5% increments, with an error not exceeding 15% opacity on any one reading and an average error not exceeding 7.5% opacity in each category of readings.

1.4 Interference from Condensed, Uncombined Water

Opacity readings of portions of plumes that contain condensed, uncombined water vapour shall not be used to determine compliance with opacity standards.

1.5 Procedures

Determinations should be made by an observer qualified in accordance with the procedure in the Appendix.

1.5.1 ***Position.*** Stand at a distance that provides a clear view of the emissions with the sun oriented in the 140° sector to your back. Make observations from a position such that your line of vision is, as nearly as possible, perpendicular to the plume direction and, when observing the opacity of emissions from rectangular outlets (e.g., roof monitors), open baghouses, approximately perpendicular to the longer axis of the outlet. The line of sight should not include more than one plume when multiple stacks are involved,

1.5.2 ***Field Records.*** Record on a field data sheet (Figure 1) the name of the plant, emission location, type of facility, observer's name and affiliation, and the date. At the time opacity readings are initiated and completed, record the time, estimated distance to the emission location, approximate wind direction, estimated wind speed, description of the sky condition (presence and colour of clouds), and plume background.

RECORD OF VISUAL DETERMINATION OF OPACITY

Page ______ of ______

DATE ____________	POINT OF EMISSIONS ____________
COMPANY ____________	HEIGHT OF DISCHARGE POINT ____________
LOCATION ____________	HOURS OF OBSERVATION ____________
TEST NUMBER ____________	OBSERVER ____________
TYPE FACILITY ____________	OBSERVER CERTIFICATION DATE ____________
CONTROL DEVICE ____________	OBSERVER AFFILIATION ____________

Record the following information prior to and upon completion of observations at each source. If observations are made over an extended period of time, additional recordings should be made as applicable.

CLOCK TIME:	INITIAL	_____:_____	a.m.	FINAL	_____:_____ a.m.
		_____:_____	p.m.		_____:_____ p.m.

OBSERVER LOCATION

Distance to discharge ____________

Direction from discharge ____________

Height of observation point ____________

BACKGROUND DESCRIPTION ____________

WEATHER CONDITIONS

Wind direction ____________

Wind speed ____________

Ambient temperature ____________

SKY CONDITIONS ____________

(clear, overcast, cloudy, etc.)

PLUME DESCRIPTION

Colour ____________

Distance visible ____________

MINUTES OF NONCOMPLIANCE ____________

FIGURE 1 FIELD DATA SHEET

1.5.3 ***Observations.*** Make opacity observations at the point of greatest opacity in a portion of the plume where there is no condensed water vapour. Do not look continuously at the plume, but observe it momentarily at 15-second intervals.

1.5.3.1 *Attached Steam Plumes (Figure 2).* When condensed water vapour is present within the plume as it emerges from the emission outlet, make opacity observations beyond that point in the plume where condensed water vapour is no longer visible. Record the approximate distance from the emission outlet to the point at which the observations are made.

1.5.3.2 *Detached Steam Plumes (Figure 2).* When water vapour in the plume condenses and becomes visible away from the emission outlet, the opacity of emissions should be evaluated at the emission outlet prior to condensation of water vapour.

1.5.4 ***Recording Observations.*** Record opacity observations to the nearest 5% at 15-second intervals on an observational record sheet (Figure 3). A minimum of 24 observations are required. Each momentary observation recorded represents the average opacity of emissions for a 15-second period.

1.6 Calculations

Opacity is determined as an average of 24 consecutive observations recorded at 15-second intervals. Sets of 24 observations need not be consecutive in time but must not overlap. Calculate and record the average opacity for each set of observations.

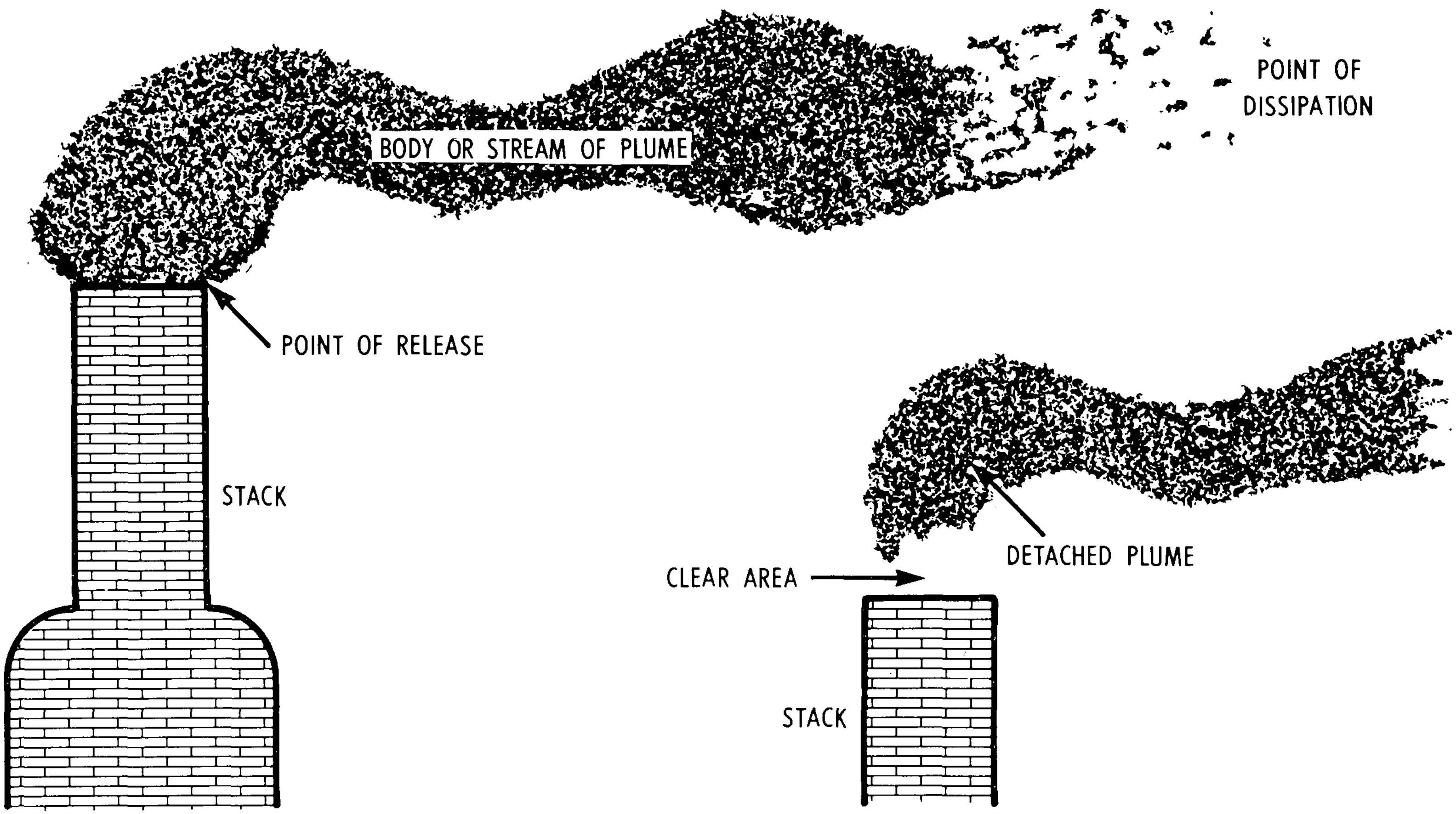
2 METHOD B - TRANSMISSOMETER SYSTEMS FOR CONTINUOUS MEASUREMENT OF OPACITY

2.1 Principle

Transmissometry is a direct measurement of the attenuation of visible radiation (opacity) by particulate matter. Light having specific spectral characteristics is projected from a lamp across the emission to a light sensor. The light is attenuated due to absorption and scatter by particulate matter in the emission. The opacity of the emission is defined as the percentage of visible light attenuated. Transparent stack emissions do not attenuate light and therefore have a transmittance of 100% or an opacity of 0%. Opaque stack emissions attenuate all visible light and have a transmittance of 0% or an opacity of 100%. The precision of a continuous monitoring system is evaluated by use of neutral density filters. Tests of a transmissometer system are performed to determine zero drift, calibration drift, and response time characteristics.

2.2 Applicability

This method is applicable to continuous monitoring systems measuring the opacity of emissions. Specifications for continuous measurement of visible emissions are given in terms of design, performance, and installation parameters. These specifications contain test procedures, installation



GENERAL STRUCTURE OF ATTACHED AND DETACHED PLUMES, RESPECTIVELY

FIGURE 2 STRUCTURE OF A PLUME

OBSERVATION RECORD

Page ______ of ______

DATE ______________________
COMPANY ______________________ OBSERVER ______________________
LOCATION ______________________ TYPE FACILITY ______________________
TEST NUMBER ______________________ POINT OF EMISSIONS ______________________

Hr	Min	Seconds				Steam plume (check if applicable)		Comments
		0	15	30	45	Attached	Detached	
	0							
	1							
	2							
	3							
	4							
	5							
	6							
	7							
	8							
	9							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							

FIGURE 3 OBSERVATIONAL RECORD SHEET

OBSERVATION RECORD

Page ______ of ______

DATE ____________________
COMPANY ____________________ OBSERVER ____________________
LOCATION ____________________ TYPE FACILITY ____________________
TEST NUMBER ____________________ POINT OF EMISSIONS ____________________

		Seconds				Steam plume (check if applicable)		
Hr	Min	0	15	30	45	Attached	Detached	Comments
	30							
	31							
	32 33							
	34							
	35							
	36							
	37							
	38							
	39							
	40							
	41							
	42							
	43							
	44							
	45							
	46							
	47							
	48							
	50							
	51							
	52							
	53							
	54							
	55							
	56							
	57							
	58							
	59							

FIGURE 3 (CONT.)

requirements and data computation procedures for evaluating the acceptability of continuous monitoring systems,subject to approval by the Minister.

2.3 Definitions

2.3.1 ***Continuous Monitoring System:*** Equipment for the continuous determination of opacity in an emission. Continuous monitoring systems consist of the following major subsystems:

2.3.1.1 *Sampling Interface:* The window or membrane that protects the analyzer from the emission.

2.3.1.2 *Analyzer:* The portion of the system that senses the transmitted light and generates an output signal that is a function of the pollutant opacity.

2.3.1.3 *Data Recorder:* The portion of the system that processes the analyzer output to provide a permanent record of opacity.

2.3.2 ***Transmissometer:*** The sampling interface and the analyzer.

2.3.3 ***Span:*** The value of opacity that corresponds to the maximum data display output. The span is set according to Section 2.4.1.

2.3.4 ***Calibration Error:*** The difference between the opacity reading indicated by the continuous monitoring system and the known values of a series of test standards. The test standards are a series of calibrated optical filters or screens.

2.3.5 ***Zero Drift:*** The change in output over a stated period of normal continuous operation at zero opacity.

2.3.6 ***Calibration Drift:*** The change in output over a stated period of normal continuous operation at a known up-scale value, which should be within the normal operating range of the system.

2.3.7 ***System Response:*** The time from a step change in opacity in the stack (at the input to the system) to the time at which 95% of the corresponding final opacity value, is displayed on the data recorder.

2.3.8 ***Operational Test Period:*** A minimum time that a continuous monitoring system is expected to operate within certain performance specifications without unscheduled maintenance, repair, or adjustment.

2.3.9 ***Transmittance:*** The fraction of incident light transmitted through an optical medium of interest.

2.3.10 ***Opacity:*** The fraction of incident light attenuated by an optical medium of interest. Opacity (O) and transmittance (T) are related as follows:

$$O = 1 - T$$

2.3.11 ***Optical Density:*** A logarithmic measure of the amount of light attenuated by an optical medium of interest. Optical density (D) is related to transmittance and opacity as follows:

$$D = -\log_{10} T$$
$$D = -\log_{10} (1 - O)$$

2.3.12 ***Peak Optical Response:*** The wavelength of maximum sensitivity of the instrument.

2.3.13 ***Mean Spectral Response:*** The wavelength which bisects the total area under the curve obtained pursuant to Section 2.9.3.1.

2.3.14 ***Angle of View:*** The maximum (total) angle of radiation seen by the photodetector assembly of the analyzer.

2.3.15 ***Angle of Projection:*** The maximum (total) angle that contains 95% of the radiation projected from the lamp assembly of the analyzer.

2.3.16 ***Pathlength:*** The depth of emission in the light beam between the receiver and the transmitter of a single-pass transmissometer, or the depth of emission between the transceiver and reflector of a double-pass transmissometer. Two pathlengths are defined:

2.3.16.1 Monitor Pathlength: The depth of emission at the point where the continuous monitoring system is installed.

2.3.16.2 Emission Outlet Pathlength: The depth of emission at the point where emissions are released to the atmosphere.

2.4 Apparatus

2.4.1 ***Calibrated Filters.*** Optical filters with neutral spectral characteristics and known optical densities to visible light, or screens known to produce specified optical densities, are required. Calibrated filters with accuracies certified by the manufacturer to within ±3% must be used. Low-, mid- and high-range filters with nominal optical densities are required in order to span the transmissometer at the opacity levels given in Table 1.

It is recommended that filter calibrations be checked with a well-collimated photopic transmissometer of known linearity prior to use. The filters must be large enough to attenuate the entire light beam of the transmissometer.

2.4.2 ***Data Recorder.*** Analog chart recorder or other suitable device with input voltage range compatible with the measurement system output. The resolution of the recorder's data output must be sufficient to allow completion of the test procedures within the method.

2.4.3 ***Opacity Measurement System.*** An in-stack transmissometer (folded or single path) with the optical design specifications designated in Section 2.7.1, associated control units and apparatus to keep optical surfaces clean.

TABLE 1 SPAN VALUE VS. CALIBRATED OPTICAL DENSITY

Span value (percent opacity)	Calibrated filter optical densities with equivalent opacity in parenthesis		
	Low	Mid	High
50	0.1(20)	0.2(37)	0.3(50)
60	0.1(20)	0.2(37)	0.3(50)
70	0.1(20)	0.3(50)	0.4(60)
80	0.1(20)	0.3(50)	0.6(75)
90	0.1(20)	0.4(60)	0.7(80)
100	0.1(20)	0.4(60)	0.9(87 1/2)

2.5 Installation Specifications

2.5.1 ***Location.*** The transmissometer must be located across a section of duct or stack that will provide a particulate matter flow through the optical volume of the transmissometer representative of the particulate matter flow through the duct or stack. It is recommended that the monitor pathlength include the entire width or diameter of the duct or stack. Installations with a shorter pathlength must be used with caution in determining a measurement location representative of the particulate matter flow through the duct or stack.

2.5.1.1 The transmissometer location must be downstream from all particulate control equipment.

2.5.1.2 The transmissometer must be located as far from bends and obstructions as practical.

2.5.1.3 A transmissometer located in the duct or stack following a bend should, where possible, be installed in the plane defined by the bend.

2.5.1.4 The transmissometer should be installed in an accessible location.

2.5.1.5 When specified by the Minister, the owner or operator of a source must demonstrate that the transmissometer is located in a section of duct or stack where a uniform or representative particulate matter distribution exists. This determination shall be made by examining the opacity profile of the emission at a series of positions across the duct or stack while the plant is in operation at maximum or reduced operating rates or by other tests acceptable to the Minister.

2.5.2 ***Slotted Tube.*** Installations that require the use of a slotted tube shall use one of such size and blackness so as not to interfere with the free flow of the emission through the entire optical volume of the transmissometer or reflect light into the transmissometer photodetector. Light reflections may be prevented by using blackened baffles within the slotted tube to prevent the lamp radiation from impinging upon the tube walls, by restricting the angle of projection of the light and the angle of view of the photodetector assembly to less than the cross-sectional area of the slotted tube, or by other methods. The owner or operator must show that the manufacturer of the monitoring system has used appropriate methods to minimize light reflection for systems using slotted tubes.

2.5.3 Data Recorder Output. The continuous monitoring system output should permit expanded display of the span opacity on a standard 0% to 100% scale. Since all opacity standards are based on the opacity of the emission exhausted to the atmosphere, the system output should be based upon the emission outlet pathlength and permanently recorded. For sources where the monitor pathlength differs from the emission outlet pathlength, a graph should be provided to show the relationships between, (1) the recorded opacity based upon the emission outlet pathlength and, (2) the opacity of the effluent at the analyzer location (monitor pathlength). Tests for measurement of opacity are based upon the monitor pathlength. The graph necessary for conversion of the data recorder output to a monitor pathlength basis shall be established as follows:

$$\log(1 - O_1) = (D_1/D_2) \log(1 - O_2)$$

where
O_1 = opacity of the effluent based upon D_1
O_2 = opacity of the effluent based upon D_2
D_1 = emission outlet pathlength
D_2 = monitor pathlength

2.6 Optical Design Specifications

The optical design specifications in Section 2.7.1 must be met for a measurement system to comply with the requirements of this method.

2.7 Determination of Conformity with Design Specifications

2.7.1 Design Specifications. The continuous monitoring system for measurement of opacity must be demonstrated to conform to the design specifications given below:

2.7.1.1 Peak Spectral Response. The peak spectral response should occur between 500 nm and 600 nm. Response at any wavelength below 400 nm or above 700 nm should be less than 10% of the peak response.

2.7.1.2 Mean Spectral Response. The mean spectral response should occur between 500 nm and 600 nm.

2.7.1.3 Angle of View. The total angle of view should be no greater than 5 degrees.

2.7.1.4 *Angle of Projection.* The total angle of projection should be no greater than 5 degrees.

2.7.2 ***Demonstration of Conformity.*** Conformity with the requirements of Section 2.7.1 may be demonstrated by the owner or operator of a facility or by the manufacturer of the opacity measurement system. Where conformity is demonstrated by the manufacturer, certification that the tests were performed, description of test procedures and test results should be provided by the manufacturer. If the source owner or operator demonstrates conformity, the procedures used and results obtained shall be reported.

2.7.3 ***Test Procedures.*** The general test procedures to be followed to demonstrate conformity with the requirements of Section 2.7.1 are given below. (These procedures will not be applicable to all designs and will require modification in some cases. Where analyzer and optical design are certified by the manufacturer to conform with the specified angle of view or angle of projection the respective procedures may be omitted).

2.7.3.1 *Spectral Response:* Obtain spectral data for detector, lamp, and filter components used in the measurement system from their respective manufacturers.

2.7.3.2 *Angle of View:* Set up the receiver as specified by the manufacturer. Draw an arc with radius of 3 m. Measure the receiver response to a small (less than 3 cm) non-directional light source at 5-cm intervals on the arc for 26 cm on either side of the detector centreline. Repeat the test in the vertical direction.

2.7.3.3 *Angle of Projection:* Set up the projector as specified by the manufacturer. Draw an arc with a radius of 3 m. Using a small (less than 3 cm) photoelectric light detector, measure the light intensity at 5-cm intervals on the arc for 26 cm on either side of the light source centreline of projection. Repeat the test in the vertical direction.

2.8 Continuous Monitoring System Performance Specifications

2.8.1 ***Specifications.*** The continuous monitoring system must meet the performance specifications listed in Table 2 to be considered acceptable under this method.

2.8.2 ***Test Procedures.*** The following test procedures are used to determine conformity with the performance specifications in Table 2.

2.8.2.1 *Calibration Error and Response Time Test.* These tests are to be performed prior to installation of the system on the stack and may be performed at the affected facility or at other locations, provided that proper notification is given. Set up and calibrate the measurement system, as specified by the manufacturer's written instructions, for the monitor pathlength to be used in the installation. Span the analyzer as specified in Section 2.4.1.

Calibration Error Test. Insert a series of calibration filters in the transmissometer path at the midpoint. A minimum of three calibration filters (low-, mid- and high-range) selected in accordance with Table 1 and calibrated within 3% must be used. Make a total of five

TABLE 2 PERFORMANCE SPECIFICATIONS FOR OPACITY MEASUREMENT SYSTEMS

Parameter	Specifications
Calibration error	$\leq$ 3% opacity*
Zero drift (24 h)	$\leq$ 2% opacity*
Calibration drift (24 h)	$\leq$ 2% opacity*
Response time	10 s (maximum)
Operational test period	168 h

* Expressed as sum of absolute mean value plus 95% confidence interval for the test series, calculated according to Section 2.9.2.

non-consecutive readings for each filter. Record the measurement system output readings in percent opacity (Figure 4).

System Response Test. Insert the high-range filter in the transmissometer path five times and record the time required for the system to respond to 95% of final zero and high-range filter values (Figure 5).

2.8.2.2 *Field Test for Zero Drift and Calibration Drift.* Install the continuous monitoring system and perform the following alignments:

Preliminary Alignments. As soon as possible after installation, and once a year thereafter when the facility is not in operation, perform the following optical and zero alignments:

Optical Alignment - Align the light beam from the transmissometer on the optical surfaces located across the emission (i.e., the retroflector or photodetector as applicable) in accordance with the manufacturer's instructions.

Zero Alignment - Perform zero alignment after the transmissometer has been optically aligned, the transmissometer mounting is mechanically stable (i.e., there is no movement of the mounting due to thermal contraction of the stack, duct, etc.) and a clean stack condition has been determined by a steady zero opacity condition. This alignment is made by balancing the continuous monitor system response so that any simulated zero check coincides with an actual zero check performed across the monitor pathlength of the clean stack.

CALIBRATED NEUTRAL DENSITY FILTER DATA (See Section 2.8.2.1)			
Low Range _______% opacity Mid Range _______% opacity High Range _______% opacity Span Value _______ % opacity			
Date of Test ______________________	Location of Test ______________________		
Run #	Calibrated filter[1]	Analyzer reading % opacity	Differences[2] % opacity
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

	Low	Mid	High
Mean difference	____	____	____
Confidence interval	____	____	____
Calibrated error = Mean Difference[3] + C.I.	____	____	____

[1]Low, mid or high range
[2]Calibration filter opacity – analyzer reading
[3]Absolute value

FIGURE 4 CALIBRATION ERROR TEST

Date of test ______________________________

Location ______________________________

Span filter ______________________________ % opacity

Analyzer span setting ______________________________ % opacity

Upscale	1	______________	seconds
	2	______________	seconds
	3	______________	seconds
	4	______________	seconds
	5	______________	seconds
Downscale	1	______________	seconds
	2	______________	seconds
	3	______________	seconds
	4	______________	seconds
	5	______________	seconds

Average response ______________________________ seconds

FIGURE 5 DATA SHEET FOR SYSTEM RESPONSE TEST

Span - Span the continuous monitoring system at the opacity specified in Section 2.4.1 and offset the zero setting at least 10% of the span so that negative drift can be quantified.

Final Alignments. After the preliminary alignments have been completed and the facility has been started up and reaches normal operating temperature, recheck the preliminary alignments. If the alignment has shifted, realign the optics, record any detectable shift in the opacity measured by the system that can be attributed to the optical realignment, and notify the Minister. This condition may not be objectionable if the facility operates within a fairly constant, adequately narrow range of operating temperatures that does not produce significant shifts in optical alignment during normal operation of the facility. Where facility operations produce fluctuations in the effluent gas temperature that result in significant misalignments, the Minister may require improved mounting structures or relocation of the transmissometer.

Conditioning Period. After completing the post-startup alignments, operate the system normally for an initial 168-hour conditioning period.

Operational Test Period. After completing the conditioning period, operate the system for an additional 168 hours retaining the zero offset. The system should monitor the emission at all times except when being zeroed or calibrated. At 24-hour intervals the zero and span shall be checked according to the manufacturer's instructions. The procedures used should involve a system check of the analyzer internal mirrors and all electronic circuitry including the lamp and photodetector assembly, and production of a simulated zero opacity condition and a simulated upscale (span) opacity condition, as viewed by the receiver. The manufacturer's written instructions may be used if they are as stringent as these procedures. Zero and span the transmissometer, clean all optical surfaces exposed to the emission, realign optics and make any adjustments to the calibration of the system daily. These zero and calibration adjustments and optical realignments are allowed only at 24-hour intervals or at such shorter intervals as the manufacturer's written instructions specify. Automatic corrections made by the measurement system without operator intervention are allowable at any time. The magnitude of any zero or span drift adjustments shall be recorded. During the operational test period, record the following at 24-hour intervals:

a) the zero reading and span readings after the system is calibrated (these readings should be set at the same value at the beginning of each 24-hour period);

b) the zero reading after each 24 hours of operation, but before cleaning and adjustment;

c) the span reading after cleaning and zero adjustment, but before span adjustment (Figure 6).

Zero setting ______________ (see Section 2.8.2.2) Span setting ______________ Date of test ______________				
Date and time	Zero reading (Before cleaning and adjustment)	Zero drift (Δ Zero)	Span reading (After cleaning and zero adjustment but before span adjustment)	Calibration drift (Δ Span)

Zero drift = Mean zero drift* ______ + C.I. (Zero) ______
= ______

Calibration drift = Mean span drift* ______ + C.I. (Span) ______
= ______

*Absolute value

FIGURE 6 ZERO AND CALIBRATION DRIFT TEST

2.9 Calculations

2.9.1 Mean Value of Data Set.

$$x = \frac{1}{n} \sum_{i=1}^{n} x_i$$

where

x = mean value of data set

x_i = individual values of data set

Σ = sum of the individual values

n = number of individual data points

2.9.2 Two-sided 95% Confidence Interval of the Average Mean Value

$$C.I._{95} = \frac{t_{.975}}{n\sqrt{n-1}} \sqrt{n\,(\Sigma\, x_i^2) - (\Sigma\, x_i)^2}$$

where

$C.I._{95}$ = 95% confidence interval estimate of the average mean value

Σx_i = sum of individual data points

$t_{.975}$ = see Table 3 for values

2.9.3 Data Analysis and Reporting

2.9.3.1 *Spectral Response:* Combine the spectral data obtained in accordance with Section 2.7.3.1 to develop the effective spectral response curve of the transmissometer. Report the wavelength at which the peak response occurs, the wavelength at which the mean response occurs and the maximum response at any wavelength below 400 nm and above 700 nm expressed as a percentage of the peak response as required by Section 2.7.2.

2.9.3.2 *Angle of View:* Using the data obtained in accordance with Section 2.7.3.2, calculate the response of the receiver as a function of viewing angle in the horizontal and vertical directions (26 cm of arc with a radius of 3 m equal 5°). Report relative angle of view curves as required in Section 2.7.2.

2.9.3.3 *Angle of Projection:* Using the data obtained in accordance with Section 2.7.3.3 calculate the response of the photoelectric detector as a function of projection angle in the horizontal and vertical directions. Report relative angle of projection curves as required in Section 2.7.2.

2.9.3.4 *Calibration Error:* Using the data from Section 2.8.2.1 (Figure 4), subtract the known filter opacity value from the value shown by the measurement system for each of the 15 readings. Calculate the mean and 95% confidence interval of the five difference values at each test filter value according to Sections 2.9.1 and 2.9.2. Report the sum of the absolute mean difference and the 95% confidence interval for each of the three test filters.

TABLE 3 VALUES FOR $t_{.975}$

n	$t_{.975}$
2	12.706
3	4.303
4	3.182
5	2.776
6	2.571
7	2.447
8	2.365
9	2.306
10	2.262
11	2.228
12	2.201
13	2.179
14	2.160
15	2.145
16	2.131

The values in this table are already corrected for n−1 degrees of freedom.
Use n equal to the number of samples as data points.

2.9.3.5 *Zero Drift:* Using zero opacity values measured every 24 hours during the field test (Section 2.8.2.2), calculate the differences between zero point after cleaning, aligning, and adjustment, and the zero value 24 hours later just prior to cleaning, aligning and adjustment. Calculate the mean value of these points and the confidence interval according to Sections 2.9.1 and 2.9.2. Report the sum of the absolute mean value and the 95% confidence interval.

2.9.3.6 *Calibration Drift:* Using the span value measured every 24 hours during the field test, calculate the differences between the span value after cleaning, aligning and adjustment of zero and span, and the span value 24 hours later just after cleaning, aligning, and adjustment of zero and before adjustment of span. Calculate the mean value of these points and the confidence interval according to Sections 2.9.1 and 2.9.2. Report the sum of the absolute mean value and the confidence interval.

2.9.3.7 *Response Time:* Using the data from Section 2.8.2.1, calculate the time interval from filter insertion to 95% of the final stable value for all up-scale and down-scale traverses. Report the mean of the 10 up-scale and down-scale test times.

2.9.3.8 *Operational Test Period:* During the 168-hour operational test, the continuous monitoring system should not require any corrective maintenance, repair, replacement, or adjustment other than that clearly specified in the manufacturer's operation and maintenance manuals as routine during a 1-week period. If the system is operated within the specified performance parameters and does not require corrective maintenance, repair, replacement or adjustment, other than that specified above during the test period, the operational test can be successfully concluded. Failure of the continuous monitoring system to meet these requirements necessitates a repetition of the 168-hour test. Portions of the test which were satisfactorily completed need not be repeated. Failure to meet any performance specification(s) calls for a repetition of the 1-week operational test and that specific portion of the test required by Section 2.8.2 related to demonstrating compliance with the failed specification. All maintenance and adjustments required shall be recorded. Output readings must be recorded before and after all adjustments.

APPENDIX - QUALIFICATION AND TESTING OF OBSERVERS

A-1 PRINCIPLE

Candidates for positions as qualified observers are first familiarized with black and white plumes of known opacity produced by a calibrated smoke generator. They are then required to demonstrate proficiency in assigning opacity readings to black and white plumes presented during a certification test.

A-2 CERTIFICATION REQUIREMENTS

To receive certification as a qualified observer, a candidate must be able to assign opacity readings in 5% increments to 25 different black plumes and 25 different white plumes, with an error not exceeding 15% opacity on any one reading and an average error not exceeding 7.5% opacity in each category. Candidates shall be tested according to the procedures described in Section A-4.4. Smoke generators must be equipped with a smoke meter that meets the requirements of Section A-3.

Certification is valid for only 6 months, after which the qualification procedure must be repeated in order to retain certification.

A-3 APPARATUS

Smoke Generator. Any smoke generator used for observer training and testing should be equipped with a smoke meter installed to measure opacity across the diameter of the smoke generator stack. The smoke meter output must display in-stack opacity based upon a pathlength equal to the stack exit diameter, on a full 0% to 100% chart recorder scale. The smoke meter optical design and performance must meet the specifications shown in Table A-1.

A-4 PROCEDURES

A-4.1 Calibration - General

Calibrate the smoke meter, as prescribed in Section A-4.2 prior to each smoke-reading test. At the completion of each test, check the zero and span drift and if the drift exceeds ± 1% opacity, correct the condition before conducting any subsequent test runs. At the time of installation, the smoke meter should be demonstrated to meet the specifications listed in Table A-1. This demonstration must be repeated following any subsequent repair or replacement of the photocell or associated electronic circuitry including the chart recorder or output meter or every 6 months, whichever occurs first.

A-4.2 Calibration Procedure

Calibrate the smoke meter after allowing a minimum warmup of 30 minutes, by alternately producing simulated opacities of 0% and 100%. When stable response at 0% or 100% is noted, adjust

TABLE A-1 SMOKE METER DESIGN AND PERFORMANCE SPECIFICATIONS

Parameter	Specification
Light Source	Incandescent lamp operated at nominal rated voltage
Spectral response of photocell	Photopic (daylight spectral response of the human eye – reference 1)
Angle of view	15° maximum total angle
Angle of projection	15° maximum total angle
Calibration	± 3% opacity, maximum
Zero and span drift	± 1% opacity, 30 min
Response time	≤ 5 s

the smoke meter to produce an output of 0% or 100% as appropriate. Repeat this calibration until stable 0% and 100% readings are produced without adjustment. Simulated 0% and 100% opacity values may be produced by alternately switching the power to the light source on and off, respectively, while the smoke generator is not producing smoke.

A-4.3 Smoke Meter Evaluation

Evaluate smoke meter design and performance as follows:

A-4.3.1 ***Light Source.*** Verify from manufacturer's data and from voltage measurements made at the lamp, as installed, that the lamp is operated within ± 5% of the nominal rated voltage.

A-4.3.2 ***Spectral Response of Photocell.*** Verify from manufacturer's data that the photocell has a photopic response; i.e., the spectral sensitivity of the cell closely approximates the standard spectral-luminosity curve for photopic vision given in reference 1.

A-4.3.3 ***Angle of View.*** Check construction geometry to ensure that the total angle of view of the smoke plume, as seen by the photocell, does not exceed 15°. The total angle of view may be calculated as follows:

$$\theta = 2 \tan^{-1} (d/2L)$$

where θ = total angle of view
d = sum of photocell diameter + diameter of limiting aperture
L = distance from photocell to limiting aperture

The limiting aperture is the point in the path between the photocell and the smoke plume where the angle of view is most restricted. In smoke generator smoke meters this is normally an orifice plate.

A-4.3.4 ***Angle of Projection.*** Check construction geometry to ensure that the total angle of projection of the lamp on the smoke plume does not exceed 15°. The total angle of projection may be calculated as follows:

$$\theta = 2 \tan^{-1} (d/2L)$$

where θ = total angle of projection
d = the sum of the length of the lamp filament + the diameter of the limiting aperture
L = the distance from the filament to the limiting aperture

A-4.3.5 ***Calibration Error.*** Using neutral density filters of known opacity, check the error between the actual response and the theoretical linear response of the smoke meter. This check is accomplished by first calibrating the smoke meter according to Section A-4.2 and then inserting a series of three neutral-density filters with nominal opacities of 20%, 50%, and 75% in the smoke meter pathlength. Filters calibrated within ± 2% should be used. Care should be taken when inserting the filters to prevent stray light from affecting the meter. Make a total of five non-consecutive readings for each filter. The maximum error on any one reading shall be 3% opacity.

A-4.3.6 ***Zero and Span Drift.*** Determine the zero and span drift by calibrating and operating the smoke generator normally for one hour. The drift is measured by checking the zero and span at the end of this time.

A-4.3.7 ***Response Time.*** Determine the response time by producing a series of five simulated 0% and 100% opacity values and observing the time required to reach stable response. Opacity values of 0% and 100% may be simulated by alternately switching the power to the light source off and on while the smoke generator is not operating.

A-4.4 Certification Procedure

The certification test consists of showing the candidate a complete run of 50 plumes - 25 black plumes and 25 white plumes - produced by a smoke generator. Plumes within each set of 25 black and 25 white runs should be presented in random order. The candidate assigns an opacity value to each plume and records his observations on a suitable form. At the completion of each run of 50 readings, the score of the candidate is determined. If a candidate fails to satisfy the requirements stipulated in Section A-2, the complete run of 50 readings must be repeated in any retest.

The test may be administered as part of a smoke school or training program, and may be preceded by training or familiarization runs of the smoke generator during which candidates are shown black and white plumes of known opacity.

REFERENCES

1. Condon, E.U. and Odishaw, H. *Handbook of Physics*, Table 3.1, p.8-52 McGraw - Hill Co. New York, N.Y. (1958).

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