Designation: D 6216 – 03

Standard Practice for Opacity Monitor Manufacturers to Certify Conformance with Design and Performance Specifications[1]

This standard is issued under the fixed designation D 6216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers the procedure for certifying continuous opacity monitors. It includes design and performance specifications, test procedures, and quality assurance requirements to ensure that continuous opacity monitors meet minimum design and calibration requirements, necessary in part, for accurate opacity monitoring measurements in regulatory environmental opacity monitoring applications subject to 10 % or higher opacity standards.

1.2 This practice applies specifically to the original manufacturer, or to those involved in the repair, remanufacture, or resale of opacity monitors.

1.3 Test procedures that specifically apply to the various equipment configurations of component equipment that comprise either a transmissometer, an opacity monitor, or complete opacity monitoring system are detailed in this practice.

1.4 The specifications and test procedures contained in this practice have been adopted by reference by the United States Environmental Protection Agency (USEPA). For each opacity monitor or monitoring system that the manufacturer demonstrates conformance to this practice, the manufacturer may issue a certificate that states that opacity monitor or monitoring system conforms with all of the applicable design and performance requirements of 40 CFR 60, Appendix B, Performance Specification 1 except those for which tests are required after installation.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres

2.2 *U.S. Environmental Protection Agency Document:*[3]

40 CFR 60 Appendix B, Performance Specification 1

2.3 *Other Documents:*

ISO/DIS 9004 Quality Management and Quality System Elements-Guidelines[4]

ANSI/NCSL Z 540-1-1994 Calibration Laboratories and Measuring Equipment - General Requirements[4]

NIST 260-116 - Filter calibration procedures[5]

3. Terminology

3.1 For terminology relevant to this practice, see Terminology D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

Analyzer Equipment

3.2.1 *opacity*, *n*—measurement of the degree to which particulate emissions reduce (due to absorption, reflection, and scattering) the intensity of transmitted photopic light and obscure the view of an object through ambient air, an effluent gas stream, or an optical medium, of a given pathlength.

3.2.1.1 *Discussion*—Opacity (Op), expressed as a percent, is related to transmitted light, (T) through the equation:

$$Op = (1 - T)(100). \quad (1)$$

3.2.2 *opacity monitor*, *n*—an instrument that continuously determines the opacity of emissions released to the atmosphere.

3.2.2.1 *Discussion*—An opacity monitor includes a transmissometer that determines the *in-situ* opacity, a means to correct opacity measurements to equivalent single-pass opacity values that would be observed at the pathlength of the emission outlet, and all other interface and peripheral equipment necessary for continuous operation.

3.2.2.2 *Discussion*—An opacity monitor may include the following: (*1*) sample interface equipment such as filters and purge air blowers to protect the instrument and minimize

[1] This practice is under the jurisdiction of ASTM Committee D22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

[5] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 3460, Gaithersburg, MD 20899-3460.

***A Summary of Changes section appears at the end of this standard.**

contamination of exposed optical surfaces, (*2*) shutters or other devices to provide protection during power outages or failure of the sample interface, and (*3*) a remote control unit to facilitate monitoring the output of the instrument, initiation of zero and upscale calibration checks, or control of other opacity monitor functions.

3.2.3 *opacity monitor model*, *n*—a specific transmissometer or opacity monitor configuration identified by the specific measurement system design, including: (*1*) the use of specific light source, detector(s), lenses, mirrors, and other optical components, (*2*) the physical arrangement of optical and other principal components, (*3*) the specific electronics configuration and signal processing approach, (*4*) the specific calibration check mechanisms and drift/dust compensation devices and approaches, and (*5*) the specific software version and data processing algorithms, as implemented in a particular manufacturing process, at a particular facility and subject to an identifiable quality assurance system.

3.2.3.1 *Discussion*—Changing the retro-reflector material or the size of the retro-reflector aperture is not considered to be a model change unless it changes the basic attributes of the optical system.

3.2.3.2 *Discussion*—Minor changes to software or data outputs may not be considered as a model change provided that the manufacturer documents all such changes and provides a satisfactory explanation in a report.

3.2.4 *opacity monitoring system*, *n*—the entire set of equipment necessary to monitor continuously the in-stack opacity, average the emission measurement data, and permanently record monitoring results.

3.2.4.1 *Discussion*—An opacity monitoring system includes at least one opacity monitor with all of its associated interface and peripheral equipment and the specific data recording system (including software) employed by the end user. An opacity monitoring system may include multiple opacity monitors and a common data acquisition and recording system.

3.2.5 *optical density (OD)*, *n*—a logarithmic measure of the amount of incident light attenuated.

3.2.5.1 *Discussion*—OD is related to transmittance and opacity as follows:

$$OD = \log_{10} (1/T) = -\log_{10} (T) = -\log_{10} (1-Op), \quad (2)$$

where Op is expressed as a fraction.

3.2.6 *transmittance*, *n*—the fraction of incident light within a specified optical region that passes through an optical medium.

3.2.7 *transmissometer*, *n*—an instrument that passes light through a particulate-laden effluent stream and measures *in situ* the optical transmittance of that light within a specified wavelength region.

3.2.7.1 *Discussion*—Single-pass transmissometers consist of a light source and detector components mounted on opposite ends of the measurement path. Double-pass instruments consist of a transceiver (including both light source and detector components) and a reflector mounted on opposite ends of the measurement path.

3.2.7.2 *Discussion*—For the purposes of this practice, the transmissometer includes the following mechanisms (1) means to verify the optical alignment of the components and (2) simulated zero and upscale calibration devices to check calibration drifts when the instrument is installed on a stack or duct.

3.2.7.3 *Discussion*—Transmissometers are sometimes referred to as *opacity analyzers* when they are configured to measure opacity.

Analyzer Zero Adjustments and Devices

3.2.8 *dust compensation*, *n*—a method or procedure for systematically adjusting the output of a transmissometer to account for reduction in transmitted light reaching the detector (apparent increase in opacity) that is specifically due to the accumulation of dust (that is, particulate matter) on the exposed optical surfaces of the transmissometer.

3.2.8.1 *Discussion*—Dust compensation may be included as an optional feature but is not required.

3.2.8.2 *Discussion*—The dust compensation is determined relative to the previous occasion when the exposed optics were cleaned and the dust compensation was reset to zero. The determination of dust accumulation on surfaces exposed to the effluent must be limited to only those surfaces through which the light beam passes under normal opacity measurement and the simulated zero device or equivalent mechanism necessary for the dust compensation measurement. The determination of dust compensation is not required to include all surfaces exposed to the effluent or dust accumulation.

3.2.8.3 *Discussion*—The dust accumulation for all of the optical surfaces included in the dust compensation method must actually be measured. Unlike zero drift, which may be either positive or negative, dust compensation can only reduce the apparent opacity. A dust compensation procedure can correct for specific bias and provide measurement results equivalent to the *clean window* condition.

3.2.8.4 *Discussion*—In those cases where dust compensation is used, the opacity monitor must provide a means to display the level of dust compensation. Regulatory requirements may impose a limit on the amount of dust compensation that can be applied and require that an alarm be activated when the limit is reached.

3.2.9 *external zero device*, *n*—an external device for checking the zero alignment of the transmissometer by simulating the zero opacity condition for a specific installed opacity monitor.

3.2.10 *simulated zero device*, *n*—an automated mechanism within the transmissometer that produces a simulated clear path condition or low level opacity condition.

3.2.10.1 *Discussion*—The simulated zero device is used to check zero drift daily or more frequently and whenever necessary (for example, after corrective actions or repairs) to assess opacity monitor performance while the instrument is installed on the stack or duct.

3.2.10.2 *Discussion*—The proper response to the simulated zero device is established under clear path conditions while the transmissometer is optically aligned at the installation pathlength and accurately calibrated. The simulated zero device is then the surrogate, clear path calibration value, while the opacity monitor is in service.

3.2.10.3 *Discussion*—Simulated zero checks do not necessarily assess the optical alignment, the reflector status (for double-pass systems), or the dust contamination level on all optical surfaces. (See also 6.9.1.)

3.2.11 *zero alignment*, *n*—the process of establishing the quantitative relationship between the simulated zero device and the actual clear path opacity responses of a transmissometer.

3.2.12 *zero compensation*, *n*—an automatic adjustment of the transmissometer to achieve the correct response to the simulated zero device.

3.2.12.1 *Discussion*—The zero compensation adjustment is fundamental to the transmissometer design and may be inherent to its operation (for example, continuous adjustment based on comparison to reference values/conditions, use of automatic control mechanisms, rapid comparisons with simulated zero and upscale calibration drift check values, and so forth) or it may occur each time a calibration check cycle (zero and upscale calibration drift check) is performed by applying either analog or digital adjustments within the transmissometer.

3.2.12.2 *Discussion*—For opacity monitors that do not distinguish between zero compensation and dust compensation, the accumulated zero compensation may be designated as the dust compensation. Regulatory requirements may impose a limit on the amount of dust compensation that can be applied and require that an alarm be activated when the limit is reached.

3.2.13 *zero drift*, *n*—the difference between the opacity monitor response to the simulated zero device and its nominal value (reported as percent opacity) after a period of normal continuous operation during which no maintenance, repairs, or external adjustments to the opacity monitor took place.

3.2.13.1 *Discussion*—Zero drift may occur due to changes in the light source, changes in the detector, variations due to internal scattering, changes in electronic components, or varying environmental conditions such as temperature, voltage or other external factors. Depending on the design of the transmissometer, particulate matter (that is, dust) deposited on optical surfaces may contribute to zero drift. Zero drift may be positive or negative.

Calibrations and Adjustments

3.2.14 *attenuator*, *n*—a glass or grid filter that reduces the transmittance of light.

3.2.15 *calibration drift*, *n*—the difference between the opacity monitor response to the upscale calibration device and its nominal value after a period of normal continuous operation during which no maintenance, repairs, or external adjustments to the opacity monitor took place.

3.2.15.1 *Discussion*—Calibration drift may be determined after determining and correcting for zero drift. For opacity monitors that include automatic zero compensation or dust compensation features, calibration drift may be determined after zero drift or dust compensation, or both, are applied.

3.2.16 *calibration error*, *n*—the sum of the absolute value of the mean difference and confidence coefficient for the opacity values indicated by an optically aligned opacity monitor (laboratory test) or opacity monitoring system (field test) as compared to the known values of three calibration attenuators under clear path conditions.

3.2.16.1 *Discussion*—The calibration error indicates the fundamental calibration status of the opacity.

3.2.17 *external adjustment*, *n*—either (*1*) a physical adjustment to a component of the opacity monitoring system that affects its response or its performance, or (*2*) an adjustment applied by the data acquisition system (for example, mathematical adjustment to compensate for drift) which is external to the transmissometer and control unit, if applicable.

3.2.17.1 *Discussion*—External adjustments are made at the election of the end user but may be subject to various regulatory requirements.

3.2.18 *intrinsic adjustment*, *n*—an automatic and essential feature of an opacity monitor that provides for the internal control of specific components or adjustment of the opacity monitor response in a manner consistent with the manufacturer's design of the instrument and its intended operation.

3.2.18.1 *Discussion*—Examples of intrinsic adjustments include automatic gain control used to maintain signal amplitudes constant with respect to some reference value, or the technique of ratioing the measurement and reference beams in dual beam systems. Intrinsic adjustments are either nonelective or are configured according to factory recommended procedures; they are not subject to change from time to time at the discretion of the end user.

3.2.19 *upscale calibration device*, *n*—an automated mechanism (employing a filter or reduced reflectance device) within the transmissometer that produces an upscale opacity value.

3.2.19.1 *Discussion*—The upscale calibration device is used to check the upscale drift of the measurement system. It may be used in conjunction with the simulated zero device (for example, filter superimposed on simulated zero reflector) or a parallel fashion (for example, zero and upscale (reduced reflectance) devices applied to the light beam sequentially). (See also 6.9.2.)

Opacity Monitor Location Characteristics

3.2.20 *installation pathlength*, *n*—the installation flange-to-flange separation distance between the transceiver and reflector for a double-pass transmissometer or between the transmitter and receiver for a single-pass transmissometer.

3.2.21 *monitoring pathlength*, *n*—the effective single pass depth of effluent between the receiver and the transmitter of a single-pass transmissometer, or between the transceiver and reflector of a double-pass transmissometer at the installation location.

3.2.22 *emission outlet pathlength*, *n*—the physical pathlength (single pass depth of effluent) at the location where emissions are released to the atmosphere.

3.2.22.1 *Discussion*—For circular stacks, the emission outlet pathlength is the internal diameter at the stack exit. For non-circular outlets, the emission outlet pathlength is the hydraulic diameter. For rectangular stacks:

$$D = (2LW)/(L + W), \quad (3)$$

where L is the length of the outlet and W is the width of the stack exit.

3.2.23 *pathlength correction factor (PLCF)*, *n*—the ratio of the emission outlet pathlength to the monitoring pathlength.

3.2.23.1 *Discussion*—The PLCF is used to calculate the equivalent single pass opacity that would be observed at the stack exit.

3.2.23.2 *Discussion*—A number of similar terms are found in the literature, manufacturer operating manuals, and in common usage. OPLR (optical pathlength ratio) and STR (stack taper ratio) are common. The OPLR is equal to one half of the pathlength correction. Refer to the instrument manufacturer for the proper factor.

3.2.23.3 *Discussion*—**Warning—**In cases where the PLCF value is greater than typical values, (for example, greater than two) the effects of measurement errors will be significantly increased.

Opacity Monitor Optical Characteristics

3.2.24 *angle of projection (AOP)*, *n*—the total angle that contains all of the visible (photopic) radiation projected from the light source of the transmissometer at a level greater than 2.5 % of its peak illuminance.

3.2.25 *angle of view (AOV)*, *n*—the total angle that contains all of the visible (photopic) radiation detected by the photodetector assembly of the transmissometer at a level greater than 2.5 % of the peak detector response.

3.2.26 *instrument response time*, *n*—the time required for the electrical output of an opacity monitor to achieve 95 % of a step change in the path opacity.

3.2.27 *mean spectral response*, *n*—the mean response wavelength of the wavelength distribution for the effective spectral response curve of the transmissometer.

3.2.28 *optical alignment indicator*, *n*—a device or means to determine objectively the optical alignment status of opacity monitor components.

3.2.29 *peak spectral response*, *n*—the wavelength of maximum sensitivity of the transmissometer.

3.2.30 *photopic*, *n*—a region of the electromagnetic spectrum defined by the response of the light-adapted human eye as characterized in the "Source C, Human Eye Response" contained in 40CFR60, Appendix B, Performance Specification 1.

4. Summary of Practice

4.1 A comprehensive series of specifications and test procedures that opacity monitor manufacturers must use to certify opacity monitoring equipment (that is, that the equipment meets minimum design and performance requirements) prior to shipment to the end user is provided. The design and performance specifications are summarized in Table 1.

4.2 Design specifications and test procedures for (*1*) peak and mean spectral responses, (*2*) angle of view and angle of projection, (*3*) insensitivity to supply voltage variations, (*4*) thermal stability, (*5*) insensitivity to ambient light, and (*6*) an optional procedure for opacity monitors with external zero devices which regulatory agencies may require are included. The manufacturer periodically selects and tests for conformance with these design specifications an instrument that is representative of a group of instruments) produced during a specified period or lot. Non-conformance with the design specifications requires corrective action and retesting. Each remanufactured opacity monitor must be tested to demonstrate conformance with the design specifications. The test frequency, transmissometer installation pathlength (that is, set-up distance) and pathlength correction factor for each design specification test are summarized in Table 2.

TABLE 1 Summary of Manufacturer's Specifications and Requirements

Specification	Requirement
Spectral response	peak and mean spectral response between 500 and 600 nm: less than 10% of peak response below 400 nm and above 700 nm
Angle of view, angle of projection	≤4° for all radiation above 2.5 % of peak
Insensitivity to supply voltage variations	±1.0 % opacity max. change over specified range of supply voltage variation, or ±10 % variation from the nominal supply voltage
Thermal stability	±2.0 % opacity change per 40°F change over specified operational range
Insensitivity to ambient light	±2.0 % opacity max. change from sunrise to sunset with at least one 1-h average solar radiation level of ≥ 900 W/m^2
External audit filter access	required
External zero device repeatability - Optional	±1.0 % opacity
Automated calibration checks	check of all active analyzer internal optics with power or curvature, all active electronic circuitry including the light source and photodetector assembly, and electric or electro-mechanical systems used during normal measurement operation
Simulated zero check device	simulated condition during which the energy reaching the detector is between 90 and 190 % of the energy reaching the detector under actual clear path conditions
Upscale calibration check device	check of the measurement system where the energy level reaching the detector is between the energy levels corresponding to 10 % opacity and the highest level filter used to determine calibration error
Status indicators	manufacturer to identify and specify
Pathlength correction factor security	manufacturer to specify one of three options
Measurement output resolution	0.5 % opacity over measurement range from -5 % to 50 % opacity, or higher value
Measurement and recording frequency	sampling and analyzing at least every 10 s: calculate averages from at least 6 measurements per minute
Instrument response time	≤10 s to 95 % of final value
Calibration error	≤3 % opacity for the sum of the absolute value of mean difference and 95 % confidence coefficient for each of three test filters
Optical alignment indicator - (uniformity of light beam and detector)	clear indication of misalignment at or before the point where opacity changes ±2 % due to misalignment as system is misaligned both linearly and rotationally in horizontal and vertical planes
Calibration device repeatability	≤1.5 % opacity

4.3 This practice includes manufacturer's performance specifications and test procedures for (*1*) instrument response time, (*2*) calibration error, (*3*) optical alignment sight performance - homogeneity of light beam and detector. It also