Designation: ~~D7520 – 09~~ D7520 – 13

Standard Test Method for Determining the Opacity of a Plume in the Outdoor Ambient Atmosphere[1]

This standard is issued under the fixed designation D7520; 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 test method describes the procedures to determine the opacity of a ~~plume.~~ plume, using digital imagery and associated hardware and software. The aforementioned plume is caused by particulate matter emitted from a stationary point source in the outdoor ambient ~~environment using digital imagery and associated software and hardware.~~environment.

1.2 The opacity of emissions is determined by the application of a Digital Camera Opacity Technique (DCOT) that consists of a Digital Still Camera, Analysis Software, and the Output Function's content to obtain and interpret digital images to determine and report plume opacity.

1.3 This method is suitable to determine the opacity of plumes from zero (0) percent to one hundred (100) percent.

1.4 This test method is not applicable to stacks with internal diameters greater than 7.0 ~~ft.~~ft (2.13 m).[2]

1.5 Conditions that shall be considered when using this method to obtain the digital image of the plume include the plume's background, the existence of condensed water in the plume, orientation of the Digital Still Camera to the plume and the sun (see Section 8).

1.6 This standard describes the procedures to certify the DCOT, hardware, software, and method to determine the opacity of the plumes.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *U.S. Environmental Protection Agency (USEPA) Document:*[4]

USEPA Method 9 Visual Determination of the Opacity of Emissions from Stationary Sources, 40 CFR, Part 60, Appendix A-4

2.3 *Institute of Electrical and Electronics Engineers (IEEE) Document:*[5]

IEEE 12207-2008 Systems and Software Engineering—Software Life Cycle Processes (ISO/IEC 12207:2008(E)), Edition: 2nd, Institute of Electrical and Electronics Engineers, 01-Feb-2008, 138 pages, ISBN: 9780738156637

2.4 *Japanese Electronic and Information Technology Industries Association (JEITA) Document:*

Exchangeable Image File Format (EXIF) for Digital Still Cameras: Joint Photographic Experts Group: JPEG file format version 2.21, JEITA CP-3451-1 (English version) dated 2003-09; http://www.jeita.or.jp/english/standard/list/list.asp?cateid=1&subcateid=4

2.5 *International Organization for Standardization (ISO) Standard:*[6]

ISO 9001:2000(s)

[1] This test method is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

Current edition approved ~~Nov. 1, 2009~~Dec. 1, 2013. Published ~~January 2010~~January 2014. ~~DOI:10.1520/D7520-09.~~Originally approved in 2009. Last previous edition approved in 2009 as D7520 – 09. DOI:10.1520/D7520-13.

[2] The 7.0 ft limitation was set as a reasonable boundary for the initial issuing of this test method due to there being a limited amount of data for large diameter stacks.

[3] 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.

[4] Available from United State Environmental Protection Agency (USEPA), Ariel Rios Bldg, 1200 Pennsylvania Ave., NW, Washington, DC 20460, http://www.epa.org.

[5] Available from Institute of Electrical and Electronics Engineers, Inc., (IEEE), 1828 L St., NW, Suite 1202, Washington, DC 20036-5104, http://www.ieee.org.

[6] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3. Terminology

3.1 For definitions of terms used in this test method, refer to Terminology D1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *analysis software*—software that when combined with a defined operating environment: *a*) inputs images captured by the Digital Still Camera image capture devices; *b*) produces opacity measurements from the combination of human interaction, open or proprietary calculations and algorithms, and image content viewing; *c*) and then output said opacity measurement along with Analysis Software's configuration, image source documentation and other environmental parameters.

3.2.2 *certified*—for the purpose of this standard, certified refers to achieving or excelling the requirements described in this method.

3.2.3 *DCOT certification package*—for the purpose of this standard, certification package refers to 300 images (150 white smoke and 150 black smoke) captured against at least two different backgrounds.

3.2.4 *DCOT operator*—refers to the human operating the DCOT system who records the digital still images with the Digital Still Camera and then determines plume opacity with the Analysis Software.

3.2.5 *Digital Still Camera*—an image capture device used to collect store and forward digital still images to the Analysis Software for analysis as defined by the DCOT vendor's certification documentation.

3.2.6 *image transfer file*—an electronic file that contains the image captured by the Digital Still Camera and its associated environment documentation that is consistent with EXIF 2.1 JPG (or higher) format and is input to the Analysis Software. All of the digital images obtained by a DCOT system shall be reviewed by a qualified human DCOT operator to assess if the digital images are acceptable (for example, no obvious errors in the digital images).

3.2.7 *opacity*—measurement of the degree to which particulate emissions reduce the intensity of transmitted photopic light and obscure the view of an object through an effluent gas stream of a given path length in ambient air.

3.2.8 *opacity source*—any source that produces emissions that are visible to the human eye.

3.2.9 *output function*—human readable information documenting the image being analyzed and configuration of the Analysis Software used, the opacity measurement and the other required environment variables defined (for example, view angle, wind direction).

3.2.10 *run*—For the purpose of this standard, run or smoke school run refers to 50 consecutive images (25 white and 25 black). Smoke schools identify Runs with a number (normally 1-10), a date, and a location. Smoke schools may allow certification between numbered runs (that is, black smoke from Run 1, and white smoke from Run 2.)

4. Summary of Test Method

4.1 A Digital Still Camera is used to capture a set of digital images of a plume against a contrasting background. Each image is analyzed with software that determines plume opacity by comparing a user defined portion of the plume image where opacity is being measured in comparison to the background providing the contrasting values. The Analysis Software is used to average the opacities from the series of digital images taken of the plume over a fixed period of time. The software is also used to archive the image set utilized for each opacity determination including the portion of each image selected by the operator.

4.2 The following conditions must be followed to make a valid opacity determination:

4.2.1 The image must be captured in a JPEG format that adheres to the EXIF 2.1 (or higher) standard.

4.2.2 The image must be captured with the sun located behind the Digital Still Camera and within a 140° sector directly behind the Digital Still Camera (see Table 1 for schematic).

4.2.3 The image must be captured perpendicular to the direction of plume travel.

~~4.2.4 Digital enhancement capabilities of the Digital Still Camera (that is, flash, optical filters, digital zoom, and image stabilization) shall not be used. However, the Digital Still Camera's optical zoom may be used when capturing the digital still image.~~

4.2.4 The ambient light must be sufficient to show a clear contrast between the plume and its background.

4.2.5 The portion of the plume selected for opacity determination shall not contain condensed water vapor.

4.2.6 The selected portions of each image representing the visible plume and the uniform background must contrast sufficiently for the software to differentiate between the plume and its background.

4.2.7 The portion of the plume selected for opacity determination shall represent the part of the plume with the highest apparent opacity, excluding water vapor, as determined by the DCOT operator.

4.2.8 The area of the digital image to be analyzed for opacity shall be centered in the digital image when taking the photograph.

4.2.9 Each DCOT vendor shall provide training for operators of their DCOT system. The training shall include the content of the "Principles of Visual Emissions Measurements and Procedures to Evaluate those Emissions Using the Digital Camera Optical Technique (DCOT)" (Annex A1) and a description of how to operate that specific DCOT system that passed smoke school.

TABLE 1 Example of Field Data Record when Determining Plume Opacity with DCOT

Company name:

Company location:

Test Identification No.:

Date:

Type of facility:

Process unit:

Operating capacity or mode for process:

Control device:

Operational status of control device:

Height of emission point and estimation method:

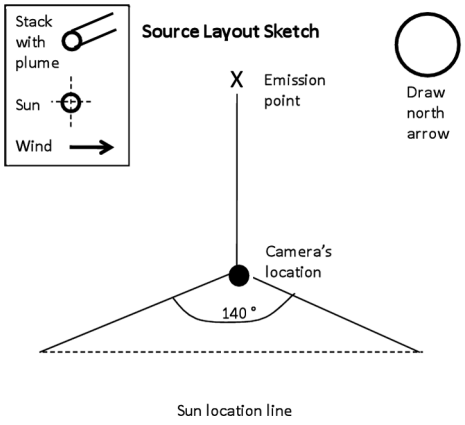
Operator name:

Operator affiliation:

DCOT certification date:

DCOT certified by:

Camera's manufacturer, model, and serial number:



	Initial	Final
CLOCK TIME		
CAMERA LOCATION		
Distance to discharge		
Vertical angle of emission point to camera		
Angle of sun to back of camera		
Height of emission point relative to camera		
ENVIRONMENTAL CONDITIONS		
Background of plume		
Wind direction		
Wind speed		
Ambient temperature		
Relative humidity		
Sky condition (for example, clear, partially cloudy, overcast)		
PLUME DESCRIPTION		
Color		
Distance between discharge and location where opacity is determined		
NUMBER CAPTURED IMAGES		
ADDITIONAL INFORMATION		

Operator signature: _____ Date: _____

5. Significance and Use

5.1 Air permits from regulatory agencies often require measurements of opacity from stationary air pollution point sources in the outdoor ambient environment. Opacity has been visually measured by certified smoke readers in accordance with USEPA (USEPA Method 9). DCOT is also a method to determine plume opacity in the outdoor ambient environment.

5.2 The concept of DCOT was based on previous method development using Digital Still Cameras and field testing of those methods.[7,8] The purpose of this standard is to set a minimum level of performance for products that use DCOT to determine plume opacity in ambient environments.

[7] Du, K., Rood, M. J., Kim, B. J., Kemme, M. R., Franek, B. J., and Mattison, K., Quantification of Plume Opacity by Digital Photography, *Environmental Science & Technology*, 41, 3, DOI: 10.1021/es061277n, 2007a, pp. 928-935.

[8] Du, K., Rood, M. J., Kim, B. J., Kemme, M. R., Franek, B. J., Mattison, K., and Cook, J., Digital Optical Method to Quantify the Visual Opacity of Plumes in the Field, *J. Air and Waste Management Association*, DOI:10.3155/1047-3289.57.7.836, 57, 2007b, pp. 836-844.

6. Interferences

6.1 *Contrast*—As the contrast between the color of the plume and the background decreases, the observed opacity decreases. To achieve maximum opacity, the opacity shall be measured at a point where the maximum contrast exists between the plume and the background.

6.2 *Luminescence*—Low light levels adversely impact the determination of plume opacity. Adequate natural light must be available to illuminate the plume and background during the period the images are captured. This method shall only be used during daytime conditions.

6.3 *Steam Plumes*—Steam plumes (or condensed water vapor) cause significant errors in measuring opacity, and occur in two distinct modes as either attached plumes or detached plumes.[9] When either condition is noted to exist, the camera operator must record sufficient images to document the type of plume observed and the relative position of the exhaust stack with relationship to the point the opacity measurement is made.

6.3.1 *Attached Steam Plumes*—When condensed water vapor is present within the plume as it emerges from the emission outlet, opacity images shall be made beyond the point in the plume at which condensed water vapor is no longer visible. The operator shall record the approximate distance from the emission outlet to the point in the plume at which the images are made (Table 1).

6.3.2 *Detached Steam Plume*—When water vapor in the plume condenses and becomes visible at a distinct distance from the emission outlet, the opacity of emissions shall be evaluated at the emission outlet prior to the condensation of water vapor and the formation of the steam plume.

6.4 *Angle of View*—The position of the camera operator with respect to the smoke plume and sun will impact the perceived contrast between the smoke plume and the background. Changes in apparent contrast will impact the measurement of opacity using this technique and must be minimized by following the procedures specified in Section 8 of this method.

6.5 *Slant-Angle*—The path length of the plume is lengthened when a Digital Still Camera is too close to a stack. The plume shall be observed at least three stack heights away, where the slant-angle is 18° or less to reduce the effect of slant angle on the perceived opacity of the plume.

7. System Description

7.1 The DCOT system is formulated into three distinct and severable components: *(1)* Digital Still Camera, *(2)* Analysis Software and its associated computing platform, and *(3)* the Output Function. This section describes each of the components and the dependency each component has to the others.

7.1.1 The first component of the system is the Digital Still Camera. The Digital Still Camera's sole purpose with respect to the DCOT system is the acquisition of images and documentation of the pictorially represented emission source. All manufacturers of a Digital Still Camera used with the DCOT system shall meet ISO 9001 Quality Standards. The DCOT operator shall use the Digital Still ~~Camera's default auto-focus settings, default auto-exposure settings and may use optical zoom when recording the digital images of the plumes. The DCOT operator shall not use digital image control such as the flash, optical filters, digital zoom, and image stabilization of the Digital Still Camera when recording the digital images of the plume.~~ Camera in accordance with the certification documentation of the DCOT, for example, camera settings matching the certification documentation of the DCOT. The Analysis Software shall verify that such conditions were used when obtaining the digital images. The Analysis Software shall define the areas to determine plume opacity and the acceptable size of areas used to determine plume opacity. The entire digital image shall remain in its native state. The Digital Still Camera must be capable of generating EXIF 2.1 JPG (or higher) formatted output files (JEMA EXIF 2.1 JPG, 1995) and the Analysis Software shall stipulate the required values of the EXIF 2.1 JPG (or higher) file as defined in its certification documentation as described in A2.1. The Digital Still Camera performs the image acquisition function and thus images must be captured in accordance with the procedures described in Section 8 to ensure that interferences are reduced as discussed in Section 6. Once the images have been captured and stored into the resulting EXIF 2.1 JPG (or higher) file per the minimum EXIF 2.1 JPG (or higher) data requirements in Annex A2 of this standard the image capture component is complete and the Analysis Software takes over. The Digital Still Camera is dependent on the minimum image requirements of the associated Analysis Software and thus must conform to the requirements for image capture as dictated by the Analysis Software component.

7.1.2 The second component of the DCOT is the Analysis Software which reads the images captured by the Digital Still Camera, performs analysis of the image and calculates the opacity level of the pictorially represented emission from the Digital Still Camera. Analysis Software modifications are subject to procedures established in Annex A3. The Analysis Software portion of the DCOT enforces the specific requirements of the Digital Still Camera (that is, JPEG 2.1 output, or higher) and the minimum requirements of the system to support required output capabilities (that is, compliant with Method 9 and certification documentation (IEEE 12207-2008)). The configuration documentation describing the Analysis Software must include a listing of all non-proprietary components of the software, such as: *(1)* the required hardware platform (that is, processors supported), *(2)* basic input output system (BIOS) supported, *(3)* storage media required and supported, *(4)* video drivers and Dynamic Link

[9] Water droplets in steam plumes will scatter light resulting in increased plume opacity until the water evaporates, and shall not be included in the determination of opacity.