Determination of Visible Emission Opacity from Stationary Sources Using Computer-Based Photographic Analysis Systems (PRE-008)

INTRODUCTION

(a) Many stationary sources discharge visible emissions into the atmosphere, which are usually in the shape of a plume. The following method describes a technical approach for determining the visible opacity of plume emissions through the use of photographs taken of the regulated source under compliance enforcement conditions. The photographs are processed using computer software that determines visible opacity using information available from the digital or digitized images. The visible opacity determination method includes procedures for the validation of both the computer opacity analysis software system as well as performance specifications for camera hardware.

(b) The appearance of a plume as viewed by an observer depends upon a number of variables, some of which may be controllable in the field. Variables that can be controlled to an extent to which they no longer exert a significant influence upon plume appearance include: angle of the observer with respect to the plume; angle of the observer with respect to the sun; point of observation of attached and detached steam plume; and angle of the observer with respect to the plume emitted from a rectangular stack with a large length-to-width ratio. The following visible opacity determination method includes specific criteria applicable to these variables.

(c) Other variables that may not be controllable in the field are luminescence and color contrast between the plume and the background against which the plume is viewed. These variables exert an influence upon the appearance of the plume and can affect the ability of the technology to assign accurately opacity values to the observed plume. Studies of the theory of plume opacity and field studies have demonstrated that a plume is most visible and presents the greatest apparent opacity when viewed against a

contrasting background [1, 2]. Accordingly, the opacity of a plume viewed under conditions where a contrasting background is present can be assigned with the greatest degree of accuracy.

Under conditions presenting a less-contrasting background, the apparent opacity of a plume is less and approaches zero as the color and luminescence contrast decrease toward zero. As a result, significant negative bias and negative errors can be made when a plume is viewed under less contrasting conditions. A negative bias decreases rather than increases the possibility that a facility will be incorrectly cited for a violation of opacity standards as a result of observer error.

(d) The accuracy of any photographic computer software opacity determination system must be taken into account when determining possible violations of applicable opacity standards. Field demonstration studies have been undertaken to determine the accuracy and reliability by a prototype opacity measurement computer software system [3, 4, 5, 6, 7]. The results of these demonstration studies (field trials), which involved the computer analysis of over twenty thousand (20,000) photographs of smoke plumes, were used to establish achievable accuracy and system reliability standards.

1. PRINCIPLE AND APPLICABILITY

1.1 Principle. The opacity of emissions from stationary sources is determined by the application of a validated photographic computer software opacity analysis system to process the digital or digitized images of the regulated emissions.

1.2 Applicability. This method is applicable for the determination of the opacity of emissions from stationary sources.

2. PROCEDURES

The validated photographic computer software analysis system shall use the following procedures for determining the opacity of visible plume emissions from digital or digitized photographs of regulated stationary sources.

2.1 Position. Photographs of visible emissions that will be utilized to establish compliance certification shall be taken at a distance sufficient to provide a clear view of the plume with the sun oriented in the 140º sector to the photographer's back. Enhanced focus of the visible emissions through use of an optical and/or digital zoom feature may be employed in taking photographs of plume opacity.

Consistent with maintaining the above requirement, photographs of visible emissions for compliance certification purposes shall, to the extent possible, be taken from a position such that the camera's line of vision is approximately perpendicular to the plume direction and, when taking photographs of visible emissions from rectangular outlets (e.g., roof monitors, open baghouses, noncircular stacks), approximately perpendicular to the longer axis of the outlet. The camera's line of sight should not include more than one plume at a time when multiple stacks are involved, and, in any case, the photographer shall take plume emission photographs with a line of site perpendicular to the longer axis of such a set of multiple stacks.

2.2 Field Records. All photographs of regulated visible emissions shall be accompanied by records that include; 1) the name of the facility, 2) emission location, 3) facility type, 4) photographer's name and affiliation, 5) opacity computer software user's name and affiliation (if different from photographer) and 6) the date and time at which the photographs were taken. The estimated distance to the emission location, the type and magnitude of any optical feature employed (e.g., optical zoom, digital zoom, etc.), approximate wind direction, estimated wind speed, description of sky conditions (e.g., presence and color of clouds), and plume background shall be documented and recorded on a field data sheet at the time plume emission photographs are taken and provided to the regulatory authority as part of the compliance certification demonstration.

2.3 Observations. When utilizing a validated photographic computer software opacity analysis system, the opacity determination shall be made at the point of greatest opacity in that portion of the plume where condensed water vapor is not present.

2.3.1 Attached Steam Plumes. When condensed water vapor is present with the plume as it emerges from the emission outlet, photographs of the visible emission must capture that portion of the plume opacity beyond which condensed water vapor is no longer visible.

2.3.2 Detached Steam Plume. When water vapor in the plume condenses and becomes visible at a distinct distance from the emission outlet, the opacity of emission should be evaluated at the emission outlet point to the condensation of water vapor and the formation of the steam plume.

2.4 Recording Observations. The number of plume photographs required to certify regulatory compliance shall depend on the scope of the observation. When the purpose of the emission observation is to establish the presence or absence of visible opacity (i.e.,

field screening), field procedures described under Phase I field activities shall be followed. Alternatively, when the presence of visible opacity has been confirmed and verification that the visible opacity level is within regulatorially permitted limits is required, field procedures described under Phase II field activities shall be followed.

2.4.1 Phase I Field Observation Activities. To establish the presence or absence of visible opacity from a regulated source, the computer analysis of a **single** photograph taken under appropriate field conditions (Sections 2.1 and 2.2) shall be conducted using a regulatorially approved photographic computer software opacity analysis system. Results from Phase I opacity field activities confirming the absence of any visible emissions from a regulated source shall be certified by the responsible facility official. All Phase I visible opacity confirmation photographs as well as results generated by the computer software opacity analysis system shall be documented and retained by the regulated facility for a period of no less than five (5) years.

2.4.2 Phase II Field Observation Activities. Once the presence of visible opacity has been confirmed (either through application of Phase I observation activity procedures or by visible observation), determination of the visible opacity level shall be established by calculating the average opacity from a set of at least fifteen (15) individual photographs of the regulated source taken under compliance verification conditions. Each plume photograph used to establish the average visible opacity level of the regulated source shall be taken at time intervals of no less than thirty (30) seconds. Ensuring that the Phase II opacity determination test period spans at least 7.5 minutes reduces the risk that an emission spike will bias field measurement results.

2.4.3 Phase II Data Reduction. Opacity shall be determined as an average of fifteen (15) individual and consecutive plume opacity estimates as determined using a regulatorially valid photographic computer software opacity analysis system. Each of the fifteen (15) opacity determinations shall be recorded from plume emissions photographed once every thirty (30) seconds for 7.5 minutes. For each set of fifteen

(15) opacity estimates, the average opacity of the regulated air source shall be calculated by summing the opacity of the fifteen (15) opacity estimates and dividing this sum by fifteen (15). If an applicable standard specifies an averaging time requiring more than fifteen (15) observations, the average opacity for all observations made during the specified time period shall be determined.

3. QUALIFICATION AND TESTING

3.1 Certification Requirements.

3.1.1 Software. To certify a photographic computer software opacity analysis system as a regulatorially valid visible opacity measurement method, the technology must demonstrate the ability to estimate the plume opacity of a series of standard images. Specifically, the technology shall determine the visible opacity of a set of three hundred (300) regulatorially-approved standard photographs of one hundred fifty (150) black and one hundred fifty (150) white plumes generated from EPA-certified smoke generators [2]. To account for variability in technology user results, a minimum of four (4) independent technology users must apply the candidate software to determine the visible opacity of all three hundred (300) images. For the photographic computer software opacity analysis system to be considered for regulatory certification, the aggregate opacity results generated by each technology user must match the actual visible opacity levels with an average margin of error not to exceed 2.5%.

Photographs employed for software certification, which shall include plumes having visible opacity in the range of zero (0) to sixty (60) percent, shall be issued by a regulatorially approved certifying organization in random order. The administering of certification tests as well as the compilation and documentation of test results shall be conducted under the auspices of the US Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) program [8]. The ETV program develops testing protocols and verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment. Results of the

photographic computer software system certification testing shall be provided to the owner/operator of the computer technology by the ETV program office immediately following documentation of system performance.

For photographic computer software systems that pass certification testing, the technology certification shall be valid for five (5) years assuming that there is no change in software design or functionality. After five years (or sooner in the case where there has be a significant change in the computer software design and/or functionality), the technology qualification procedure must be repeated to retain certification.

3.1.2 Camera Hardware. To certify a given camera for use with a regulatorially approved computer software opacity analysis system, the camera must be able to generate photographs of one hundred fifty (150) black and one hundred fifty (150) white plumes of varying opacity from either a EPA certified smoke generator or a set of regulatorially approved and standardized plume photographs, which, when analyzed by a valid software package, determines plume opacity with an average margin of error not to exceed 2.5%. Beyond meeting the accuracy standard, cameras employed in support of the present method must be capable of taking and storing fifteen (15) photographic plume images at a rate of at least one image per thirty (30) seconds.

3.2 Certification Procedure.

3.2.1 Software Package. The certification test consists of challenging the candidate computer software opacity analysis system with regulatorially standardized smoke plume photographs. During software certification testing, the visible opacity associated with a set of three hundred (300) standard photographs consisting of one hundred fifty (150) black and one hundred fifty (150) white plumes of varying opacity, shall be determined. To account for variability in technology user results, a minimum of four (4) independent technology users must apply the candidate software to determine the visible opacity of all three hundred (300) images. For the photographic computer software opacity analysis

system to be considered for regulatory certification, the aggregate opacity results generated by each technology user must match the actual visible opacity levels with an average margin of error not to exceed 2.5%.

The smoke plumes, which shall be limited to an opacity range of zero (0) to sixty (60) percent, shall be produced using smoke generators equipped with EPA-certified in-stack transmissometer. Plume photographs employed for software certification shall be issued in random order by the regulatorially approved certification testing organization. Certification photographs shall be issued and quantitative testing results compiled by regulatory approved opacity technology testing organizations administered by the US Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) program [8]. Results of the computer software opacity analysis system certification testing shall be provided to the owner/operator of the candidate computer technology and all other interested parties by the ETV program office immediately following documentation of system performance.

For photographic computer software systems that pass certification testing, the technology certification shall be valid for five (5) years assuming that there is no change in computer software design or functionality. After five years (or sooner in the case where there has been a significant change in the computer software design and/or functionality), the technology qualification procedure must be repeated to retain certification.

Each set of one hundred fifty (150) black and one hundred fifty (150) white photographs of variable opacity shall be issued to the photographic computer software system in a random order established by ETV or their contractor representatives. During certification testing, the photographic computer software system must assign an opacity value to each plume photograph. To account for variability in technology user results, a minimum of four (4) independent technology users must apply the candidate software to determine the visible opacity of all three hundred (300) images. At the completion of each run of three hundred (300) opacity evaluations, the **average opacity difference**

between the photographic computer software system measurements and those reported by the EPA-certified in-stack transmissometer is computed and compared to the established margin of error of 2.5%. The average difference is computed by determining the individual opacity difference between the opacity recorded by the photographic computer software system and that recorded by the EPA-certified in-stack transmissometer for each of the three hundred (300) opacity evaluations. The sum of the individual average differences is then divided by three hundred (300) to determine the **average opacity difference**. If any photographic computer software system fails to qualify, ETV (or its contractor representatives) may re-issue a complete set of three hundred (300) photographs of regulatorially approved standard black and white smoke plumes in a retest of the computer software. The results of any retest shall be provided to the owner/operator of the candidate computer technology and all other interested parties by the ETV program office immediately following documentation of system performance.

3.2.2 Camera Hardware. The camera certification test consists of challenging the candidate camera hardware to generate three hundred (300) photographs consisting of one hundred fifty (150) black and one hundred fifty (150) white plumes of varying opacity from either: 1) observing the visible emissions from an EPA-certified smoke generator or by 2) photographing an existing set of three hundred (300) regulatorially standard plume photographs.

If camera performance is to be established by use of an EPA-certified smoke generator, photographs of the visible emissions shall be taken at a distance sufficient to provide a clear view of the plume with the sun oriented in the 140º sector to the photographer's back. Photographs shall be taken from a position such that the camera's line of vision is approximately perpendicular to the plume direction. Enhanced focus of the visible emissions through use of an optical and/or digital zoom feature may be employed.

Once certification photographs have been compiled, each shall be analyzed by using a regulatorially valid computer software opacity analysis system by a minimum of four (4)

independent technology users. In the case where a smoke generator is employed, the candidate camera hardware shall be considered certified if the resulting opacity readings match the opacity values recorded by the EPA-certified smoke generator with an average margin of error not to exceed 2.5%. Where the candidate camera hardware is employed to record images of a set of three hundred (300) regulatorially approved standard plume photographs, the camera hardware shall be considered certified if the resulting opacity readings determined by a minimum of four (4) independent technology users match the known opacity values with an average margin of error not to exceed 2.5%.

When the accuracy standard established for certifying camera hardware is achieved, the camera *meta* data shall be recorded and retained in the certification documentation. Identical camera settings shall be employed during any subsequent field measurements with the certified camera hardware.

4.0 References.

1. Federal Register (1971) "Method 9 – Visual Determination of the Opacity of Emissions from Stationary Sources" vol. 36 No. 247 December 23, 1971

2. US Environmental Protection Agency (1975) "Evaluation and Collaborative Study of Method for Visual Determination of Opacity of Emissions from Stationary Sources" Contract No. 68-02-0626

3. Environmental Security Technology Certification Program (2005) "An Alternative to EPA Method 9 – Field Validation of the Digital Opacity Compliance System (DOCS)" Final Report Project No. CP-200119 May 2005

4. Environmental Security Technology Certification Program (2005) "An Alternative to EPA Method 9 – Field Validation of the Digital Opacity Compliance System (DOCS)" Cost and Performance Report: Project No. CP-200119 February 2005

5. McFarland, M. J., Stone, D.A., Calidonna, M. J., Rasmussen, S. L., and S. H. Terry (2003) "Evaluation of the Digital Opacity Compliance System (DOCS) in High Mountain Desert Environment" *Journal of the Air and Waste Management Association* vol. 53 pp 724-730

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8. U.S. Environmental Protection Agency – Environmental Technology Verification (ETV) Program - URL http://www.epa.gov/etv/