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Project Summary

Procedures for Evaluating the Photopic Response of the Visible Emission Training School Transmissometer

The basic concept of photopic response is a major factor in the design of the smoke generator transmissometer used at visible emission training schools. The term "photopic" refers to having the daylight spectral response characteristics of the human eye. This study evaluated three transmissometer systems, the reference daylight-photopic system, the tungsten-photopic system, and the tungsten-near-photopic system, to determine whether these three systems had significantly different response characteristics. In addition, a simple procedure was developed for checking the photopic response of transmissometer systems. The responses of the tungsten-photopic and tungsten-near-photopic systems are not significantly different from each other for white or black smoke although the response of the daylight-photopic system is different than the responses of both these systems for white and black smoke. Both laboratory and field evaluations were conducted as part of this study and indicated that a simple technique using two peak response filters is adequate for determining peak response of a system. This two-filter technique is a more desirable technique than the use of multiple cutoff filters for auditing photopic response due to field simplicity.

This Project Summary was developed by EPA's Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Background

A technically and legally sound visible emission control program is based on the requirements and criteria of EPA Reference Method 9—"Visible Determination of Opacity of Emissions from Stationary Sources" (40 CFR 60, Appendix A). The specifications for the smoke generator used in the training and certification of opacity readers are summarized in Reference Method 9 as Table 9-1, "Smoke Meter Design and Performance Specifications." An essential part of the specification is verifying the photopic response of the transmissometer system.

Since the observer is certified against the opacity values measured by the transmissometer, it is essential that the transmissometer system has the same response to the light spectrum visible to the human eye. A transmissometer system that is mostly sensitive to ultraviolet or infrared light would be unacceptable because the transmissometer and the human eye would be measuring at different wavelengths.

Because many opacity training smoke generators did not employ transmissometer systems having photopic response, the 1974 revisions to Reference Method 9 added the requirement for a photopic system. According to the current specification, the operator is required to verify from manufacturer's data that the system's photocell does, in fact, have a photopic response. This specification potentially poses two problems. First, without a specific written procedure, quality assurance checks may not be made to determine if the system is photopic. Second, simply specifying that a photocell has a photopic response does not totally define a photopic system, because the system is actually composed of both the photocell and the light source. Method 9 stipulates an incandescent source but a truly photopic system would technically use a "daylight" source.

Therefore, this study was undertaken to develop a consistent quality assurance procedure for determining the photopic characteristic of the transmissometer. In addition, several types of transmissometers were tested to see if significant errors were introduced by near-photopic response.

Experimental Design

Equipment Design

A bench model transmissometer was designed and built to study the response characteristics of the three types of systems to be evaluated. All laboratory experiments were conducted using this transmissometer. The light source, photocells, and filters were varied to obtain the various transmissometer systems included in the study. The three systems evaluated were:

(1) Fully Photopic—photopic-response photocell with daylight illumination (color temperature 5500 to 6000 K). This system is totally photopic and is considered the reference standard.

(2) Partial Photopic—photopic-response photocell with normal incandescent light source (tungsten filament, color temperature 2700 to 2900 K). This system is used most commonly in field generators and technically meets the specifications of Reference Method 9 because the photocell has a photopic response and the light source is incandescent.

(3) Near-Photopic—near-photopic photocell with normal incandescent source (tungsten filament, color temperature 2700 to 2900 K). This system was frequently used in field generators before the November 12, 1974 revisions to Reference Method 9. This system does not meet the present specifications of Reference Method 9 for photopic response because the photocell is known to be near-photopic.

Laboratory Evaluation

The first phase of this study consisted of a laboratory evaluation to determine whether different response characteristics were detectable between the reference system (fully photopic) and the other systems. A primary objective of this evaluation was to determine if a simple technique could be developed and used as a field audit procedure to determine if a transmissometer system is photopic. Peak-response filters were used to determine whether response differences were detectable. Two peak-response filters were chosen for this experiment, the Kodak No. 58 and the ETA Cellulose Acetate No. 878.

The test procedure consisted of first setting up one of the transmissometer systems and conducting a zero/span test. NBS traceable filters (transmittance of 80, 49, and 25%) were used to check the transmissometer linearity. Once linearity was established, the peak-response filters were inserted and the percent transmittance noted. The zero and span were rechecked after the runs were completed. The transmissometer was then modified to the next system type and the procedure repeated.

Field Study

The next phase of the study consisted of testing the three basic transmissometers on an operating smoke generator. A smoke generator was set up to allow two transmissometers to simultaneously monitor the stack emissions. One transmissometer was set up with the reference system; this unit was identified as transmissometer 2. The other transmissometer system was set up as a partial photopic system and identified as transmissometer 1. A series of tests were conducted using both black and white smoke, and the readings from both transmissometers were recorded.

The tests were repeated using the near-photopic system identified as transmissometer 3 and the same reference transmissometer (transmissometer 2), simultaneously.

Table 1 summarizes the transmissometer system components used during the smoke generator tests.

Discussion of Results

Laboratory Evaluation

Table 2 summarizes the test results from the 14 different transmissometer system tests conducted with the No. 58 and No. 878 filters. Runs 1 through 3 were for the tungsten-photopic system (3 different tungsten sources); Run 4 was the reference system. Runs 6 through 9 were for the near-photopic photocell tungsten source system. In addition to these basic runs, several other system combinations were conducted. Run 5 combined the daylight source with a near-photopic cell, Run 10 combined the 3100 K light source (unfiltered) with a photopic detector, and Run 8 combined the 2700 K tungsten source with the near-photopic detector with the Kodak daylight filter in place. Runs 11 through 14 were conducted using two different photocells—one was a selenium cell from an old smoke generator and the other was a silicon cell with a photopic correction filter as provided by the manufacturer.

Smoke Generator Evaluation

Table 3 summarizes the results of the field test comparing the reference transmissometer system to the partial photopic transmissometer system for both black and white plumes. These data are presented graphically in Figure 1. Table 4 summarizes the results comparing the reference transmissometer system to the near-photopic transmissometer system for both black and white plumes. These data are presented graphically in Figure 2.

In both cases, the transmissometers correlated better on black smoke than on white smoke. In all cases, the differences

Table 1. *Transmissometers Systems Smoke Generator Tests*

Transmissometer 1 (T1)
- *Valtec Selenium cell #R75EB*
- *Kodak 102 photopic filter*
- *Tungsten source (2700 K)*

Transmissometer 2 (T2)
- *Valtec Selenium cell #R75EB*
- *Kodak 102 photopic filter*
- *Tungsten source (3100 K), GE EPT 2900*
- *Corning Glass Works 5900 Daylight Filter*
- *Neutral Density Filter*

Transmissometer 3 (T3)
- *Valtec Selenium cell #R75EB*
- *Tungsten source (2700 K)*

Table 2. *Results of Test Systems*

Run number	System: Cell	System: Light Source	Percent transmittance, %: Kodak No. 58	Percent transmittance, %: ETA No. 878
4	Photopic	Daylight: filtered tungsten source (5900 K)	25	46
1	Photopic	Unfiltered tungsten (2700 K) #93 bulb	21	
2	Photopic	Unfiltered tungsten (2700 K) #1141 bulb	21	42
3	Photopic	Unfiltered tungsten (2700 K) #1073 bulb	21	43
10	Photopic	Unfiltered tungsten (2900 K) #3100 bulb	21	44
5	Near-photopic	Daylight: filtered tungsten source	14	34
6	Near-photopic	Unfiltered tungsten (2700 K) #93 bulb	15	33
7	Near-photopic	Unfiltered tungsten (2700 K) #1141 bulb	15	33
9	Near-photopic	Unfiltered tungsten (2700 K) #1073 bulb	15	33
8	Near-photopic	Tungsten (2700 K)[a] #1073 bulb	15	33
11	Near-photopic[b]	Unfiltered tungsten (2700 K)	15	34
13	Near-photopic[b]	Unfiltered tungsten (2700 K)	17	35
12	Photopic [c]	Unfiltered tungsten (2700 K)	21	44
14	Photopic[d]	Unfiltered tungsten (2700 K)	23	44

[a]With daylight filter.
[b]Selenium cell (International Rectifier, Inc. 1RA15M) from old smoke generator.
[c]Selenium cell (International Rectifier, Inc.) from old smoke generator with Kodak 102 filter added.
[d]Silicon cell with photopic filter as provided from manufacturer (International Rectifier Inc., Green Blaze).

Table 3. *Summary of Smoke Generator Test Results Reference Photopic (I) vs. Tungsten Lamp Photopic Photocell (T_2) Transmissometer*

	Measured opacity, %					
	Black smoke			White smoke		
Reading number	Reference trans.	Photopic trans.[a] Uncorrected[a]	Photopic trans.[a] Corrected[b]	Reference trans.	Photopic trans.[a] Uncorrected[a]	Photopic trans.[a] Corrected[b]
1	0.5	1.0	1.5	0.5	0.5	1.0
2	4.5	6.5	7.0	4.5	4.5	5.0
3	10.0	10.5	11.0	10.0	8.0	8.5
4	14.5	15.5	16.0	15.5	11.5	12.0
5	19.5	20.0	20.5	20.5	18.0	18.5
6	24.5	24.5	25.0	25.0	21.5	22.0
7	30.5	29.0	30.0	30.5	27.0	28.0
8	36.0	34.0	35.0	36.5	31.0	32.0
9	41.0	38.0	39.0	41.0	36.5	37.5
10	47.0	43.5	44.5	45.5	40.0	41.0
11	50.0	48.0	49.0	49.0	43.5	44.5
12	56.0	54.5	56.0	54.0	49.0	50.5
13	60.0	58.0	59.5	61.0	54.5	56.0
14	70.0	67.5	69.0	72.0	64.5	66.0
15	81.5	78.0	79.0	79.5	73.5	74.5
16	92.0	89.0	90.0	91.0	87.0	88.0
17	95.5	94.0	95.0	99.0	97.5	98.5

[a]Actual measured value.
[b]Value corrected for calibration bias as measured by neutral density filters.

between the tested configurations of transmissometers were 5 percent opacity or less. The mean difference and standard deviation of the mean difference were calculated for these data. For the photopic system, the mean difference from the reference system response and the standard deviation of the mean difference were respectively, -1.1 and 1.3 percent opacity for black smoke, and -2.6 and 2.0 percent opacity for white smoke. For the near-photopic system, the mean difference and the standard deviation were -1.1 and 1.3 percent opacity for black smoke, and -2.8 and 2.1 percent opacity for white smoke, respectively.

Summary and Conclusions

The three transmissometer systems studied in this program included the reference daylight-photopic system, the tungsten-photopic system, and the tungsten-near-photopic system. The purpose of this study was to evaluate whether these three systems had significantly different response characteristics; this evaluation would permit a determination regarding the significance of the photopic specification of Reference Method 9.

Both a laboratory and field evaluation were conducted. The results of these evaluations indicate the following:

(1) A simple technique using two peak response filters which permit transmission of light only in a small (narrow) wavelength range, is adequate to determine photopic response of a system.

(2) By using the peak-response filter technique, response differences were noted among all three of the systems evaluated. These results are summarized in Table 2.

(3) The two-filter technique is more desirable than the use of multiple cutoff filters for auditing photopic response due to field simplicity. A cutoff filter is a filter that permits transmission of light only above or below a particular wavelength thereby effectively "cutting off" the transmission of light at the particular wavelength.

(4) The response of the daylight-photopic system to white and black smoke is different than the responses of the tungsten-photopic and tungsten-near-photopic systems. The difference is most pronounced for white smoke and in all cases is less than 5 percent opacity. Tables 3 and 4 summarize these results, which are graphically presented in Figures 1 and 2.

(5) The responses of the tungsten-photopic and tungsten-near-photopic systems are not significantly different from each other for black or white smoke.

(6) For the light sources evaluated (2700 K to 5900 K), the effect of different tungsten light sources used with a photopic detector is negligible.

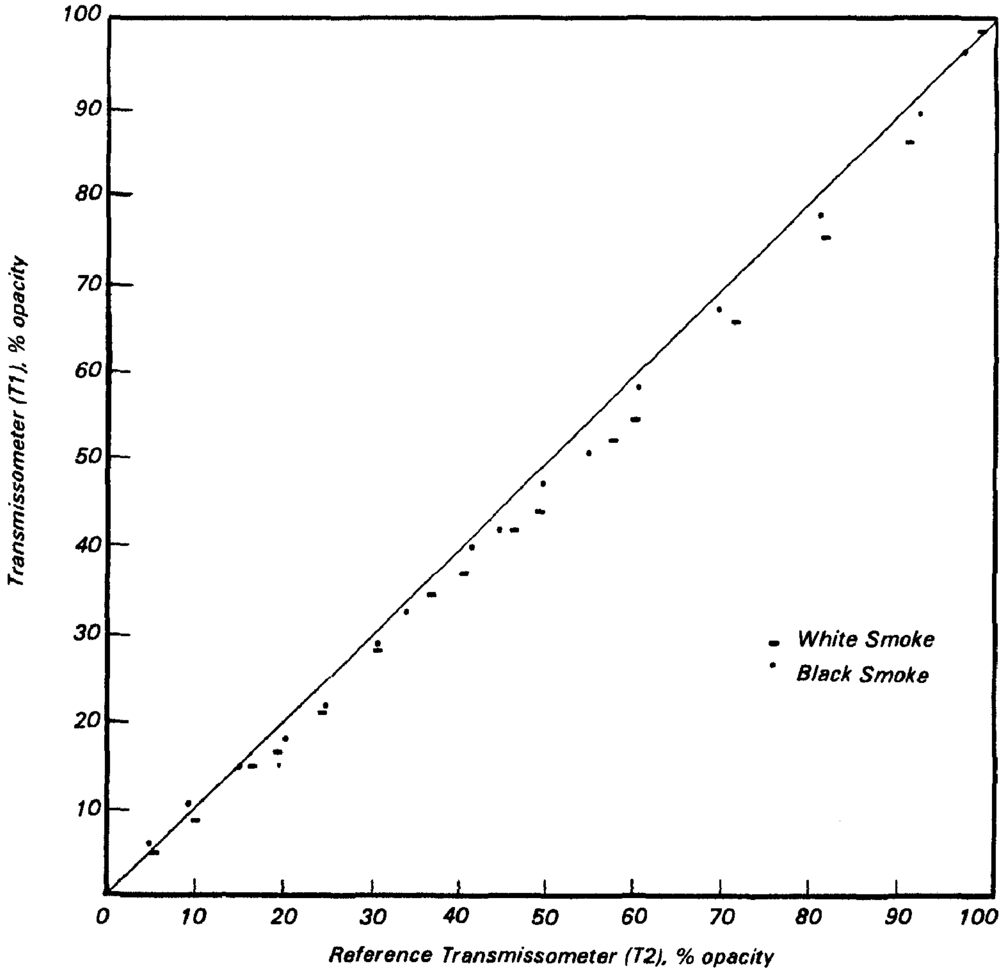

Figure 1. *Tungsten lamp photopic photocell transmissometer (T1) response compared to the reference transmissometer (T2).*

Table 4. *Summary of Smoke Generator Test Results Reference vs. Tungsten Lamp Near-Photopic Photocell Transmissometer*

	Measured opacity, %					
	Black smoke			White smoke		
		Photopic trans.[a]			Photopic trans.[a]	
Reading number	Reference trans.	Uncorrected[a]	Corrected[b]	Reference trans.	Uncorrected[a]	Corrected[b]
1	0.5	0.5	1.0	0.0	1.0	1.5
2	5.0	5.5	6.0	5.5	4.5	5.0
3	9.5	10.5	11.0	10.0	8.5	9.0
4	15.0	14.5	15.0	16.5	14.5	15.0
5	20.5	17.0	18.0	19.0	16.0	16.5
6	24.5	21.0	21.5	24.0	20.5	21.0
7	30.5	26.5	28.5	30.5	26.5	28.5
8	33.5	30.5	32.5	36.5	32.5	34.5
9	41.0	38.0	40.0	40.0	35.0	37.0
10	44.0	39.5	41.5	46.0	40.0	42.0
11	49.0	45.0	47.0	49.0	42.0	44.0
12	54.5	50.5	53.0	57.0	50.0	52.5
13	60.0	55.5	58.0	59.5	52.0	54.5
14	69.0	64.5	67.0	71.0	63.0	65.5
15	80.5	76.5	78.0	81.0	74.0	75.5
16	91.5	88.0	89.5	90.5	85.0	86.5
17	96.5	95.0	96.5	98.5	97.5	99.0

[a]Actual measured value.
[b]Value corrected for calibration bias as measured by neutral density filters.

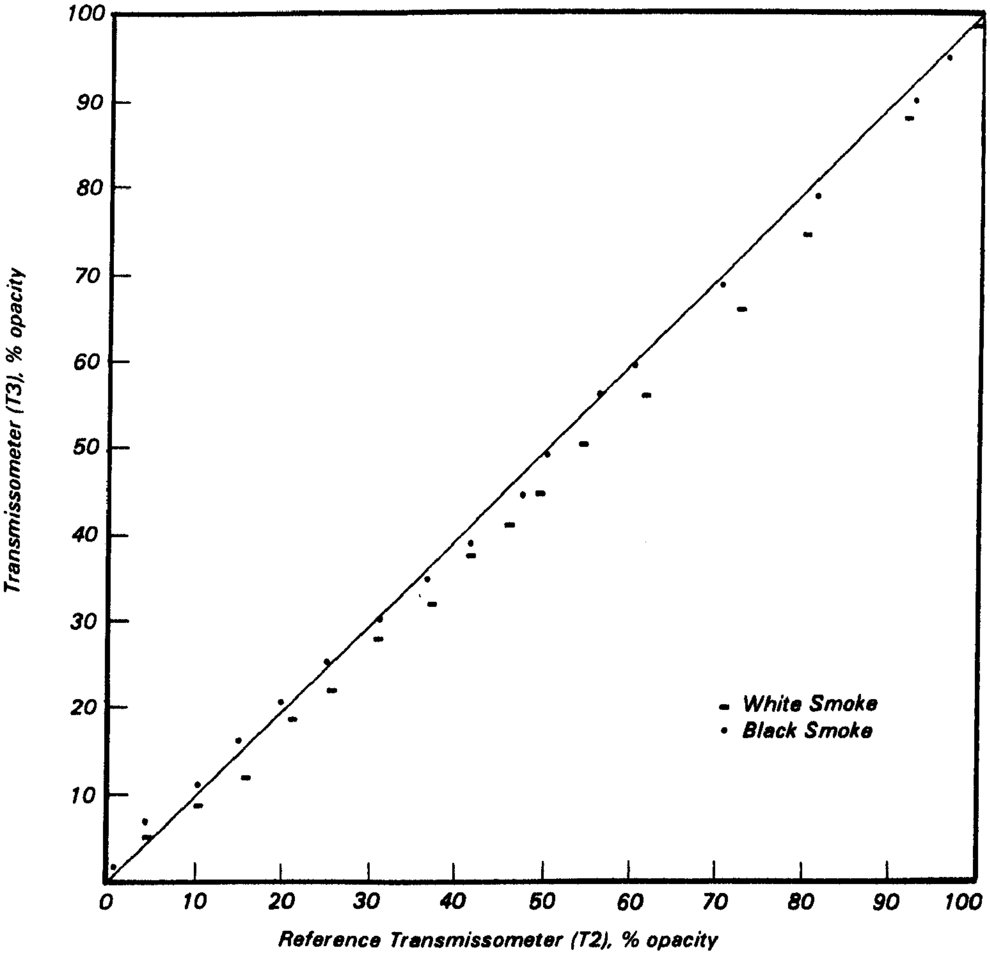

Figure 2. Tungsten lamp near-photopic photocell transmissometer (T3) response compared to the reference transmissometer (T2).

This Project Summary was authored by staff of PEDCo Environmental, Inc., Cincinnati, OH 45246-0100.
Thomas J. Logan is the EPA Project Officer (see below).
The complete report, entitled "Procedures for Evaluating the Photopic Response of the Visible Emission Training School Transmissometer," (Order No. PB 84-200 674; Cost: $10.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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