Demonstrating Compliance with Low-Level Opacity Limits

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Introduction

At present, most existing coal-fired electric utility units must meet a 20% opacity limit on a six-minute basis either in accordance with the New Source Performance Standards (NSPS) in Part 60 or by a state statute. Utilities with foresight built in an extra level of control so that compliance could still be demonstrated even if some ESP sections were out-of-service or if there were fuel changes. While testing has shown that the 20% opacity limit generally serves as a good surrogate for the NSPS particulate mass (PM) limit[1], it affords for units with a compliance buffer to provide a margin for opacity measurement error and biases. The Environmental Protection Agency (EPA) also historically made allowances to deem a unit in compliance even with a small amount of exceedances (3-5%) to reflect normal maintenance and operating issues.

However, tighter opacity limits appear to be on their way. In the steel industry, the NSPS for arc furnaces (Subpart AA or AAa) subjects those sources to 3% opacity limits. In the utility realm, some planned coal-fired boilers have already seen Prevention of Significant Deterioration (PSD) permit limits of 10% opacity, but the recent revisions to Subpart Da will push opacity limits even further.

Subpart Da Revisions – Perpetual Testing Rule?

The revisions to Subpart Da, which were promulgated in February 2006, subject new sources (i.e., sources constructed after February 28, 2005) to a PM emission limit of 0.015 lb/mmBtu (or 99.9% reduction). The initial revisions to Subpart Da proposed by EPA retained the 20% opacity limit but some argued that, since the PM limit was being significantly reduced, the opacity limit should also be reduced. In response, EPA removed the 20% opacity limit for new units in the final rule. Instead, for ESP equipped sources[2], on-going compliance is indicated either by monitoring PM directly or by monitoring a combination of opacity and ESP "voltage" and "secondary current." Sources that do not install PM continuous emissions monitoring (CEMS) must maintain opacity below 110% of the baseline value from the most recent performance test and assure that the voltage and secondary current values do not deviate by more than 10% from the baseline results. If either the opacity or the voltage and current values exceeds the baseline-related thresholds, the performance testing must be repeated within 60 days.

At 0.015 lb/mmBtu, many sources will be facing effective opacity limits in the 3 to 5% opacity range and, depending on the conditions during the test, will potentially see even lower "baseline" values. At these levels, the 10% "buffer" in the rule translates to 0.5% opacity or less. Even if one ignores the ridiculous voltage and current tolerances, tripping the opacity threshold seems practically inevitable given process variation and the degree of uncertainty currently associated with opacity measurement. Previous field demonstration projects[3] call into question PM CEMS performance[4], so utilities are between a regulatory rock and a measurement hard place.

[1] Based on the fact that many tests performed to comply with the Compliance Assurance Monitoring Rule (40 CFR Part 64) showed that if the opacity limit was satisfied, the PM limit would be met.

[2] For baghouses, a leak detection system capable of detecting PM ≤ 10 mg/m^3 is required, and retesting is triggered if the alarm period exceeds 5% of operation during any 30-day period.

[3] *Evaluation of Particulate Emission Measurement/Estimation Techniques for Coal-Fired Utility Boilers with Electrostatic Precipitators*, EPRI, Palo Alto, CA, December 2000, 10006444

[4] The PM CEMS uncertainty concerns are especially worrisome since regulators would tend to the results as a direct measure of compliance.

PS-1 Limitations

Certification requirements for continuous opacity monitoring systems (COMS) are defined within Performance Specification 1 (PS-1), which incorporates by reference the design specifications and factory testing provisions in ASTM standard D6216-98. The ASTM standard specifically states that it is intended for sources with limits that are greater than 10% opacity. Yet, while EPA acknowledged some of the problems associated with trying to measure low-level opacity, the Agency also essentially ignored them. In the preamble to PS-1, EPA suggested a conservative value for potential measurement error of about 4% opacity (although a properly operated and aligned COMS can perform better). EPA expressed that "while we recognize the potential for measurement error…we believe it is inappropriate to limit the applicability of PS-1." EPA further stated that "regardless of the potential for error in low-level COMS readings, you, the owner or operator, are expected to respond to and correct as soon as possible any indication of excess emissions," shifting the burden of trying to figure out how to make the measurements to the sources.

Measurement Uncertainty

Measurement error is the term typically used to describe the degree of uncertainty in a desired measurement value. The measurement error, the difference between the true and measured value, is typically not fixed but changes based on various influences on the measurement. Uncertainty is, thus, an indicator of the spread of the measured value around the actual value. With complex or difficult measurements, the true value may be difficult to determine, so the uncertainty is often evaluated by investigating the components that go into the measurement.

The three diagrams in Figure 1 illustrate the impact of uncertainty in COMS measurements used to indicate compliance with different level limits. The diagrams show the impact of an uncertainty of 2% opacity. For illustration purposes, it is assumed that the uncertainty fits a normal distribution, although the actual distribution is likely to be skewed since some factors (e.g., optical misalignment, dust accumulation) will only introduce positive bias.

Figure 1b illustrates the impact of uncertainty under the NSPS limit of 20% opacity for existing units. Of course, one obvious impact is that the COMS might falsely indicate an exceedance when operating near limit even if the true opacity is below the limit. For example, a COMS might indicate 21% opacity when the opacity is actually 19%. In order to avoid false positives, a source must increase its level of control corresponding to at least approximately 17% opacity. But, most sources operate far below this level. Thus, while uncertainty reduces the effective compliance buffer, it is generally only a significant concern during periods of maintenance or operational problems, which is a separate issue.

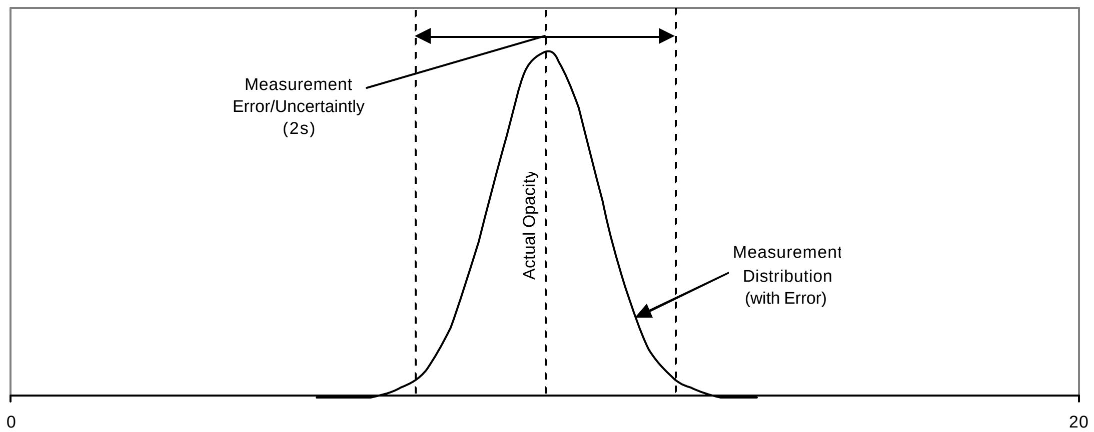

Figure 1a. Illustration of Opacity Measurement Error/Uncertainty

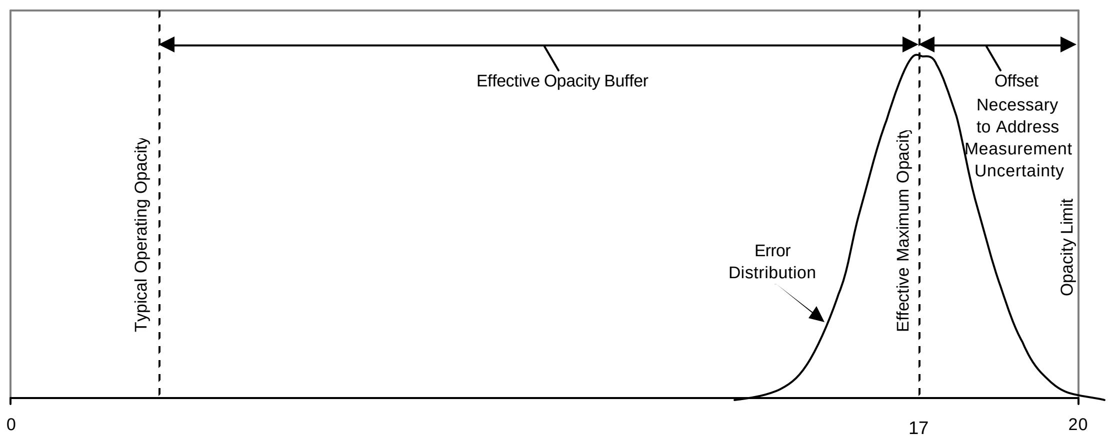

Figure 1b. Impact of Measurement Error/Uncertainty at High-Level Opacity Limits

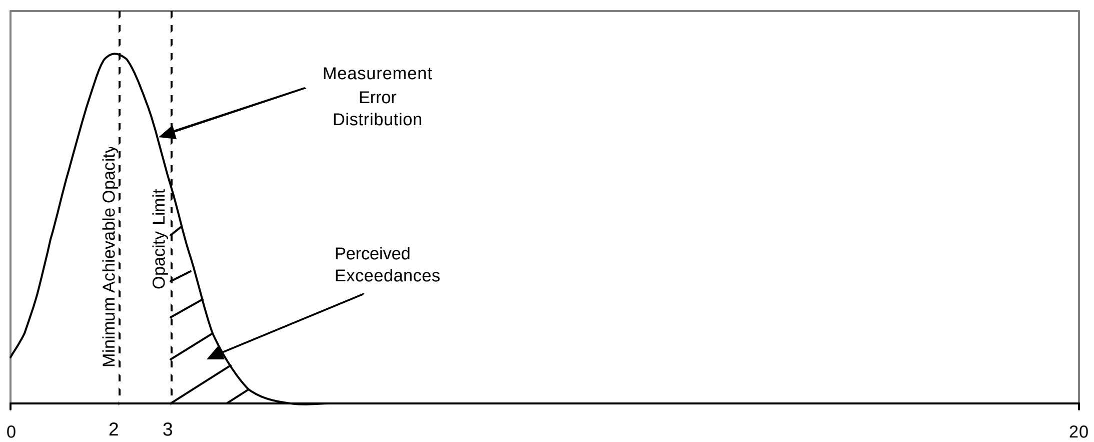

Figure 1c. Impact of Measurement Error/Uncertainty at Low-Level Opacity Limits

Figure 1c depicts a situation where a unit with a typical minimum achievable opacity of 2% might be subject to a 3% opacity limit (e.g., a new unit under Subpart Da with a baseline test opacity of ~2.7% opacity). Even though the source is capable of operating below the limit, there really is no margin because of the uncertainty. Ignoring ESP and boiler variability, which will obviously play a significant role at such levels, and assuming that the source can maintain the control at the 2% opacity level, there will be apparent "exceedances" simply due to measurement uncertainty. Such a situation will keep sources proactive with COMS maintenance in order to minimize potential drift, but there is a limited return on these activities.

CPS-001 Improvements

EPA did at least partially attempt to address low-level opacity measurements by publishing Conditional Performance Specification 1 (CPS-001). As Table 1 shows, CPS-001 tightened the design criteria:

Table 1. Comparison of PS-1 and CPS-001 Design Tolerances

Criteria	PS-1/ D6216 Tolerance*	CPS-001 Tolerance*	Note
Voltage Sensitivity	1%	0.2%	± 10% voltage variation
Thermal Stability	2%	0.3%	Δ 40°F (test does not include retro-reflector)
Ambient Light Sensitivity	2%	0.2%	Frequency modulation designs are highly effective
Optical Misalignment	2%	0.5%	Current weakness is that alignment can only be checked manually at stack
Calibration Error	3%	1%	The CPS-001 value may prove difficult based on accuracy of standard reference materials
Calibration Device Repeatability	1.5%	0.3%	95th percentile of multiple upscale measurements
Output Resolution	0.5%	0.1%	-5 to ≥ 50% opacity (D6216) -4 to ≥ 20% opacity (CPS-001)
Drift Specification	2%	NA	After initial test, data are considered valid if drift is ≤ 4%

* All tolerances expressed in terms of percent opacity

These design criteria changes represent a significant step to reduce opacity measurement uncertainty but may not be enough. If the measurement components listed in Table 1 were the only issues, the CPS-001 tolerances suggest possible uncertainties near 1% opacity, which would be the minimum viable level for sources with low opacity limits. The calibration error specification in CPS-001 may prove difficult, however, because it is unclear whether the available standard reference materials can be used to meet this level of accuracy since the filters themselves are specified to ±1% opacity. Another weakness of the CPS-001 specification is that the optical alignment requirement can currently only be checked manually. There is no test to assess the ongoing stability of the optical alignment.[5] Of course, the relatively loose PS-1 drift specification would still apply, but sources could elect to employ a more rigorous tolerance.

Other Uncertainty Considerations

CPS-001 alone will not solve the uncertainty problem, because it does not address a number of relevant opacity measurement issues. Neither CPS-001 nor PS-1 (or the current version of ASTM D6216) address the following:

- Whether significant misalignment occurs between manual checks. There is no specification to indicate the stability of the mounting or the necessary frequency for alignment checks. Current procedures also lack a way for users to quantitatively assess the error associated with a given misalignment.

- The impact of retro-reflector misalignment. Depending on the design and materials, the effect may be significant. Retro-reflector thermal sensitivity can also be an issue.

- Potential differences in retro-reflector and transceiver dust accumulation. Since the daily checks are performed on the transceiver side, asymmetry in dust accumulation can introduce error.

- Influence of design on performance test results. The optical response to such things as audit filters may be effected by the selected light source focal point.

- Stability of external zero devices (cal jigs) and certified audit filters. The spectral characteristics of the filters are important in order to match the specific bandwidth used COMS and to determine the impact of any temperature related variation in the spectral output of the light source.

- Supplemental calibration filter issues. Tighter protocols may be needed to increase low-level calibration filter accuracy. Additional procedures may also be needed for filter use to ensure consistent results. (For example, laboratory tests suggest that the angle of filter insertion relative to the light source can introduce a significant bias at angles greater than 20°.)[6]

- Clear-stack zero bias. During EPRI's extractive opacity monitor demonstration project, there was about 2% opacity difference between the clear path opacity measured when the system was not operating (i.e., there was no gas circulating in the measurement tube) and when clean, heated ambient air was blown through the system. While the extractive opacity monitor design was unusual and it is unclear whether the results could be easily translated to traditional cross-stack opacity monitors, the issue itself is believed to be universal. Similar biases of various magnitudes between clear path and "clean" operating stack values have also been noted by low level opacity sources. However, the effect has

[5] Laser and light emitting diode (LED) based opacity monitors have greatly improved light source uniformity making minor alignment variations less of an issue for newer COMS.

[6] Peeler, Jim. *Preliminary Laboratory Evaluation of "Low Level Opacity" Attenuators and Calibration Procedures – Draft Report* (March 30, 2006).

not been duplicated in lab tests and is difficult to quantify because the bias cannot be distinguished from actual opacity. The bias seemed to be related to refractive-related lensing due to the mixing of cool purge air with hotter stack gas and/or scintillation due to the temperature variations and turbulence in the measurement path.

- Path length correction factor (PLCF) issues. The traditional NSPS approach of applying a single opacity standard across an industry is problematic because the approach does not take into consideration the impact that the measurement path length has on the limit's stringency. The larger the stack diameter is, the harder the opacity standard is to meet (i.e., a higher level of emission control is required). A unit specific opacity limit or an opacity limit based on a nominal path length would be more equitable. From a measurement perspective, the fact that performance specifications do not take the path length correction factor into consideration is also an issue since the corrected opacity represents the reportable output, so the specifications should reflect this fact.

ASTM Effort

The ASTM Committee D22.03 Opacity Task Group is currently evaluating the possibility of revising D6216 to address many of the aforementioned uncertainty issues. The group has conducted a preliminary evaluation of low level opacity attenuators and calibration procedures. An initial draft of some potential revisions to D6216 has also been prepared. The task group met in April to discuss the changes to the standard as well as the results of the preliminary study and procedures for calibrating and using low-level attenuators, but ASTM is still considering the issue and it is too early to discuss specifics.

Concluding Remarks

If sources are going to have to demonstrate compliance with low-level opacity standards, it is clear that the present requirements in PS-1 and ASTM D6216 are insufficient. While an improvement, the specifications in CPS-001 do not address all the potential uncertainty concerns. ASTM is in the process of evaluating potential revisions to D6216, but is unclear whether all the issues can be readily addressed. There is no reference method for low-level opacity and sources may never be able to prove single-digit opacity values definitively (e.g., that a unit is emitting 3% opacity instead of 1% or 5% opacity at any given time). Low-level opacity applications strain the limits of COMS and some level of uncertainty may be unavoidable.

At low levels, EPA should consider alternate methods of compliance. In general, the Agency has been remiss in addressing the whole issue of uncertainty and needs to reasonable steps to resolve the problem. The notion that the burden of measurement uncertainty falls on the source is simply inequitable. If you cannot accurately measure opacity at low levels, strict continual compliance simply cannot be determined. For example, if a 3% opacity standard is imposed and the uncertainty is 2% opacity, sources should, in the very least, be deemed in compliance as long as the COMS indicates less than 5% opacity (apart from any additional allowance that might be made for process and control variations).

A significant disadvantage of a traditional COMS is that it cannot be used in saturated stacks. While their primary purpose is SO_2 control, wet scrubbers can remove considerable particulate.

Forcing sources to monitor opacity prior to the scrubber strips them of any credit for removal in the scrubber, which may be critical at the lower limits prescribed for new units.

Notwithstanding the previous comment regarding their performance, PM CEMS options should also be evaluated as a possible alternative to low-level opacity measurements. For example, lower detection levels may be possible with a back-scatter device since it is easier to measure small changes against a zero background then to measure a small attenuation of a high-level light source. Because PM CEMS tend to be either extractive or based on phenomenon within a small field, they may also be better suited for adaptation for wet stacks than COMS.

However, the application of any PM CEMS under any regulatory framework should reflect the limitations of the technology. Provisions should address the uncertainty. Because of the relative looseness of Performance Specification 11 (which applies to PM CEMS) and the sensitivity of many PM analyzers to changes in particle size distribution, it would be more reasonable to consider the measurements as indicators rather than direct measures of compliance with PM standards.

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