PM CEMS versus PM CPMS - What are they, how are they Different, and what are the Regulatory Implications of the Technologies?

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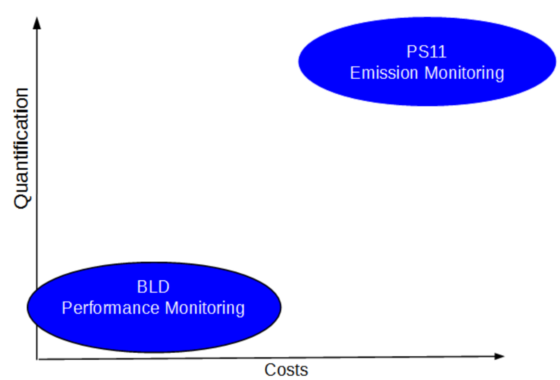
ABSTRACT

EPA has specified continuous monitoring of particulate matter (PM) across many current and pending rules. The monitoring applications range from a continuous emission monitor systems (CEMS) to continuous parametric monitoring systems (CPMS). The acronyms CEMS and CPMS are only different by one letter which makes them confusing, but there are a lot of differences in the two methods. The differences include how they are configured to how their output signals are handled. There have also been different alarm setting methods proposed by EPA for PM CPMS for different rules.

This paper will attempt to clear up the confusion by comparing the two methods and showing where they are the same, where they are different and how they are different. It will also address how these differences affect your permitted operation and what you need to know.

BACKGROUND

Particulate monitoring in the United States (US) has taken on a variety of applications. A few years ago I gave a presentation to a non-USA crowd trying to explain particulate matter (PM) monitoring in the USA. I used a chart, similar to the one on the right, with the Y-axis showing increased quantification of PM emissions and the X-axis indicated an increase in monitoring costs from left to right. In the lower left hand corner, near the zero intercept, was bag leak detectors (BLDs) with PM CEMS in the upper right corner. There was an obvious void in the middle of the chart. The BLDs are not quantitative instruments at all and minimal performance checks as compared to the PM CEMS, which is required to meet the requirements of Performance Specification 11 (PS11). Well now we have PM CPMS applications which basically fills the void space in the original chart. But the lack of direct guidance on PM CPMS has created a lot of questions and confusion on what a PM CPMS unit is versus a PM CEMS.



PM CEMS VS PM CPMS

This section will attempt to clear up any confusion between PM CEMS and PM CPMS units by identifying similarities and differences in the applications. The biggest difference in the applications is that one is and "emission" monitor and one is a "parametric" monitor. That is only one letter different, but that letter makes a big difference.

Hardware Comparison

Let's tackle the hardware difference first. The real difference in the hardware for a PM CEMS and a PM CPMS is -- NOTHING! They are exactly the same instruments with the same operational manuals.

PM CEMS is not hardware specific due to the fact that any technology for these applications must meet the requirements of Performance Specification 11 (PS11). The hardware for PM CPMS units has been defined in most rules. But the technologies named represent almost all of the technologies installed as PM CEMS in the USA to date. The technologies include:

- Light scattering (forward, back & side)
- Beta Attenuation

Several of the light scattering techniques are provide as insitu or extractive systems. Beta Attenuation is only provides as an extractive system. Extractive systems are required for wet stack conditions because they have additional hardware to handle water droplets.

Quality Assurance (QA)

The following table provides as summary of the QA requirements for PM CEMS and PM CPMS applications. The quality assurance requirements for PM CEMS is defined in PS11, but PM CPMS units are defined in a site specific monitoring plan.

<table>
<tr><th>Frequency</th><th>PM CPMS</th><th>PM CEMS</th></tr>
<tr><td>Initially</td><td rowspan="4">A site-specific monitoring plan to apply sound practices for installing, calibrating and operating the PM CPMS.</td><td>7-day Drift (it is a CEMS)</td></tr>
<tr><td>Daily</td><td>Zero / Span Checks (4% Limit) –- Optical Integrity for light-scattering/extinction-types –- Sample Volume for systems using volume to calculate PM</td></tr>
<tr><td>Quarterly</td><td>Absolute Correlation Audit (ACA) - Challenge Detector with known reference --- Sample Volume</td></tr>
<tr><td>Annually</td><td>Just another Quarter (see above)</td></tr>
</table>

PS11 is a good guidance for creating your site specific monitoring plan since it is what EPA is used to seeing and the monitoring applications are very similar. Note that the equipment you purchase should already be able to do most of the QA checks required due because the systems were originally developed for PM CEMS applications.

Testing, Alarm Limits & Compliance

Table 1 provides and overview of the testing and compliance requirements between PM CEMS and PM CPMS applications.

Table 1

	PM CPMS	PM CEMS
Initial Testing	3 runs from Compliance Test	15 data points, ~3 days of testing
Annual Testing	3 runs, but establishes new Operating Limit for the following year	RRA (3 runs at normal conditions)
Equipment	Specific Technologies	Not Technology Specific
Establish Limit	Annually	----
Curve Audit	-----	RCA, 3 yrs = 12 Data Points
Max Operating Limit	Extrapolate up to 75% of Limit or Average results if > 75% of Limit (see Equations 1 & 2 below)	100% of permitted limit or 125% of highest PM CEMS response in initial curve
Compliance Period	30-day Rolling Average	30-day Rolling Average

Compliance

You can see that the compliance period for both application is a 30-day rolling average. But the compliance limits are very different. A CEMS can potentially utilize their entire permitted PM limit, based on their calibration curve. The CEMS can also be limited by the data used in their calibration curve because EPA only allows their to extrapolate 25% above the highest data point in the existing curve. Therefore how you setup your curve in a CEMS application is very important to future operations and your limits.

A CPMS application is allowed to extrapolate up to 75% of their permitted limit as long as the data used to establish the operating parametric limit (OPL) was below 75% of the limit. If the data used for the OPL was greater than 75% of the limit, then the average of the data becomes your operating limit. It should be noted that CPMS compliance is only concentration based and is not associated with a gas flow rate. Therefore you could have higher PM data during reduced air flow conditions.

Exceeding the operating limits of both curves has an affect on retesting, which is discussed later in this section.

Testing & Alarm Limits

In both cases, the results of EPA Method 5 (M5), or an M5 version, are used to scale or calibrate the PM device output. With a CEMS, the output of the monitor is calibrated to produce a PM concentration based on specific conditions of the monitor (e.g., extractive monitors operate at higher temperatures and insitu monitors operate at stack conditions). These results are then used with associated stack gas flow data to calculate the mass emission rate of PM which can be used for determination of compliance. A PS11 application requires a minimum of 15 data points for the initial curve development and then 12 data points every three (3) years for a Relative Curve Audit (RCA). Both the initial curve and the RCA have to be conducted at three (3) different PM concentration levels and meet certain data requirements. Since the RCA is on a 3 year cycle, the 2 years in between requires testing at normal or base concentration conditions. This testing is called a Relative Response Audit (RRA). So if all goes according to plan and you generate a representative curve in your initial testing, you will audit and operate under that curve going forward and operate with the full PM limit defined in the permit.

Testing for a CPMS unit only requires three (3) runs annually. Each year the results of these runs are used to establish a new operating parametric limit (OPL). The OPL is identified by scaling the monitor's output, using a simple linear equation, to the compliance units, e.g., lbs/MMBTU, lbs/Ton Clinker, etc. These results are then scaled through the instrument's zero reading to create a linear regression curve.

If the results of the testing is less than 75% of the compliance limit, then the facility can extrapolated the curve up to 75% of the compliance limit and use 75% of the compliance limit as the OPL. If the results of the testing are greater than 75% of the compliance limit then the OPL limit is equal to the average results of the test.

The following equations are used to calculate the OPL when extrapolated to 75%.

$$O_L = I_z + \frac{0.75(E_L)}{R}$$

Equation 1: OPL 75% Extrapolation

Where:

- OL = Operating/Compliance Limit
- Iz = PM CPMS Instrument (milliamps) at Zero (0) PM
- EL = Emission Limit
- R = The ratio of the emission limit per PM CPMS output from performance test results

The OL units will be different for different rules and facilities.

- Cement – lbs PM/ton-clinker
- EGU – lbs PM/MWh
- Boiler – lbs PM/MMBtu

$$R = \frac{(E_a)}{(I_a - I_z)}$$

Equation 2: Calculation of Emission Limit Ratio

Where:

- R = The ratio of the emission limit per PM CPMS output from performance test results
- Ea = Average Emissions Results from the 3 compliance test runs
- Ia = Average PM CPMS Instrument Output (milliamps) from the 3 compliance test runs
- Iz = PM CPMS Instrument Output (milliamps) at Zero (0) PM

The emission limit ratio (R) will be on the same units as the OL above.

- Cement – lbs PM/ton-clinker per PM CPMS output
- EGU – lbs PM/MWh per PM CPMS output
- Boiler – lbs PM/MMBtu per PM CPMS output

Retesting

With both CEMS and CPMS applications there are conditions that can trigger retesting. These retesting points are important to understand when establishing the testing criteria and insuring continuous compliance.

CEMS applications have two (2) retesting triggers. They are both based on the highest analyzer output used to establish the calibration curve. If any of the following conditions occur the analyzer output exceeds the highest data point used to create the existing calibration curve.

The greater of:

Greater than 125% of Highest Analyzer Response from Initial Curve or an Analyzer Response that corresponds to 50 percent of the emission limit for:

- 24 consecutive hours
- more than 5 percent of your PM CEMS operating hours for the previous 30-day period

The facility has 60 days from when the trip event occurred to conduct at least 3 test runs under same conditions (e.g., at least the same level of analyzer response) and show they were not out of compliance.

Retesting for a CPMS application is trigger if the facility exceeds the site-specific 30-day rolling average limit. If this occurs, another Performance Test must be conducted within 45 days of the exceedence.

Comparison of CPMS Alarm Set-points

During the 2013 IT3 Conference, information was presented on the different methods being proposed by EPA for establishing alarm limits for CPMS applications. This section will revisit some of that information. Based on additional information this section will focus on the extrapolation curves and the associated testing.

The 2013 presentation used data generated by RMB Consultants ("RMB") in Raleigh, NC. RMB had similar questions about the methods as they related to their client base, primarily the power industry. RMB reviewed the three proposed CPMS OPL methods at that time using approximately six (6) months of 1-minute average data. This data was generated at one of their client's site during the evaluation of three (3) PM monitors. Table 2 shows RMB's results for the 75% extrapolation only since the other two methods are not relevant at this time.

It should be noted that only RMB and their client know the site location, the PM monitoring technologies & manufacturers being used, and the mounting & configuration if the analyzers. The only thing we know is that all monitors were located on the same stack.

Since stack testing was conducted as part of this of the monitor evaluation, RMB used those results, along with the EPA proposed methods, to create OPLs as if the monitors were CPMS applications. Then they compared the OPLs for each monitor to 30-day rolling average of the operating data. Their review revealed that the PM data indicated the facility would be out of compliance a large percentage of the time. But since these monitors were being evaluated as PM CEMS applications, complete calibration curves were generated for all units. The CEMS curves showed that all of the units were in compliance the entire time period.

Table 2
RMB Data Summary

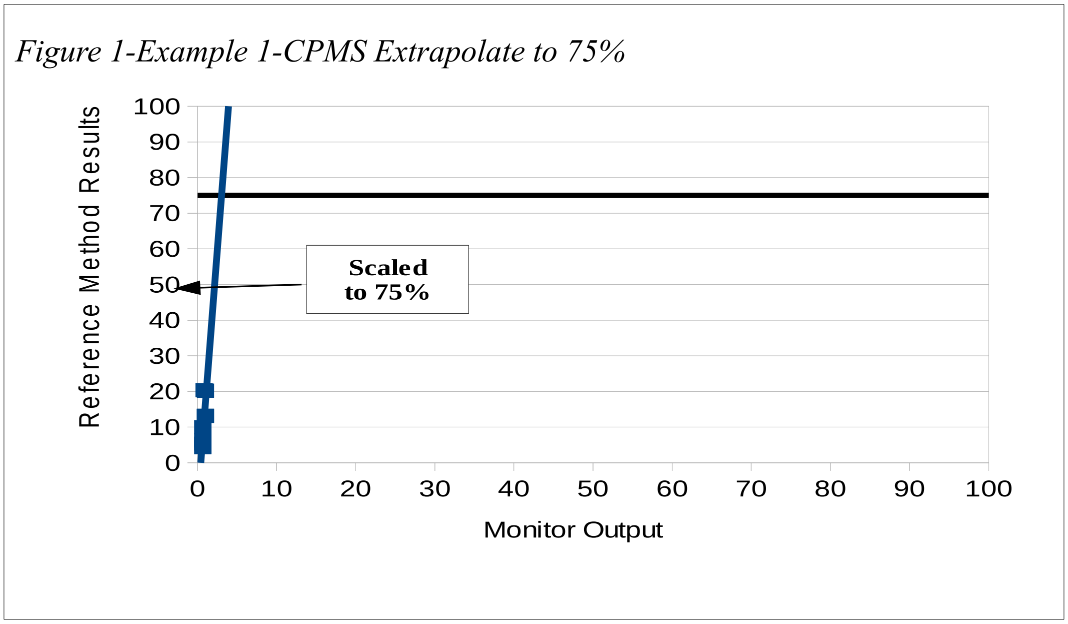
Approach Used	CPMS-1		CPMS-2		CPMS-3	
	Exceedences	Time	Exceedences	Time	Exceedences	Time
75% - New Limit	18	13.00%	0	0.00%	32	23.00%
75% - Current Limit	0	0.00%	0	0.00%	0	0.00%

With experience on over 40 PM CEMS programs, we did not understand how or why this could happen. We felt that additional studies were needed. But we did not have access to any of the RMB data. Therefore we used information from other PM CEMS programs in hopes to better understand the reason why the RMB data did not match with our experience.

Please note that all data used in the following examples has been normalized to a zero (0) to 100% scale at the request of the facilities.

EXAMPLE 1

Our first evaluation used data from a PM CEMS calibration test from a dry scrubber system that utilized a baghouse for PM control. The base PM concentration data from the PS11 testing was used to create an extrapolation using the EPA's method up to 75% of the limit, Figure 1.



This gets even more puzzling when you bring in the PS11 data for the entire curve, Figure 2. This type of situation supports RMB's data and may explain why there was a very high exceed rate for a CPMS unit when the CEMS does not indicate any compliance issues. The resulting extrapolation curve is very steep because the monitor's output was very consistent, but the M5 results had more variability.

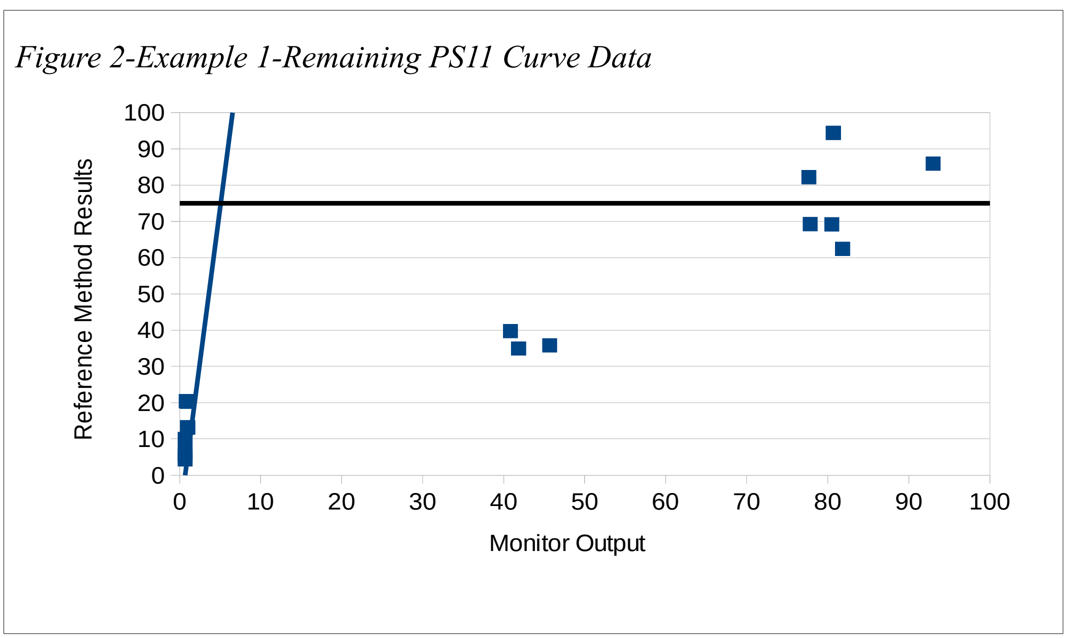
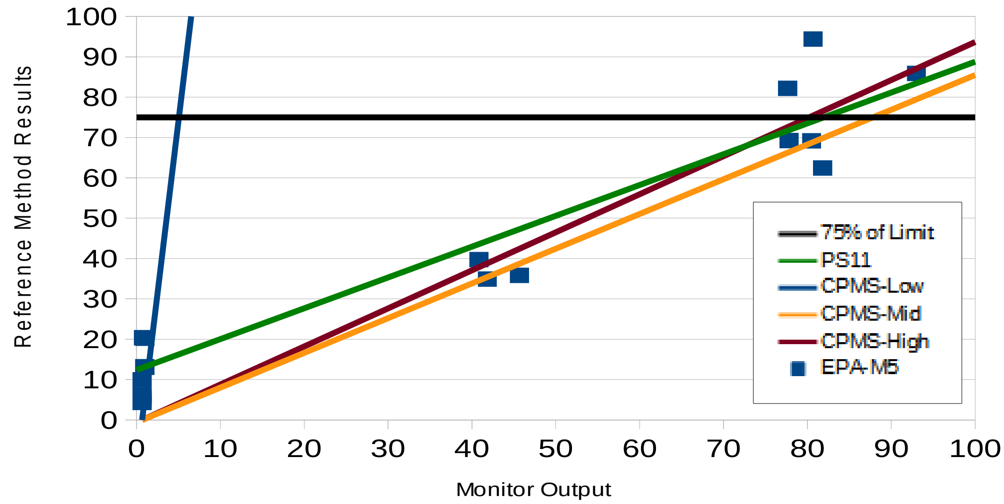


Figure 3 shows the actual CEMS calibration curve along with different CPMS extrapolation curves based on different data groups from the testing. From this data set it appears that a better CPMS response curve is obtained when the PM concentration is near 50% of the permitted limit versus the base PM concentration.

Figure 3-Example 1-Relationships with Different Data Sets



EXAMPLE 2

We were so proud of this that we continued to see if other data sets could support the same basis. Using another PS11 data set from a dry scrubber and baghouse, we applied the same thought process from the previous example and generated the following CPMS curve using the base PM results, Figure 4.

Figure 4: Example 2—Base PM & CPMS 75% Extrapolation

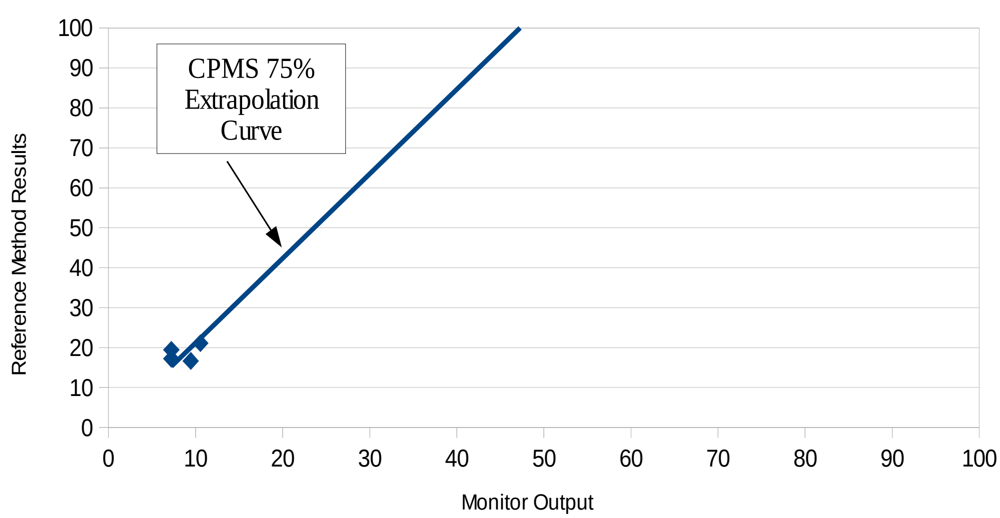
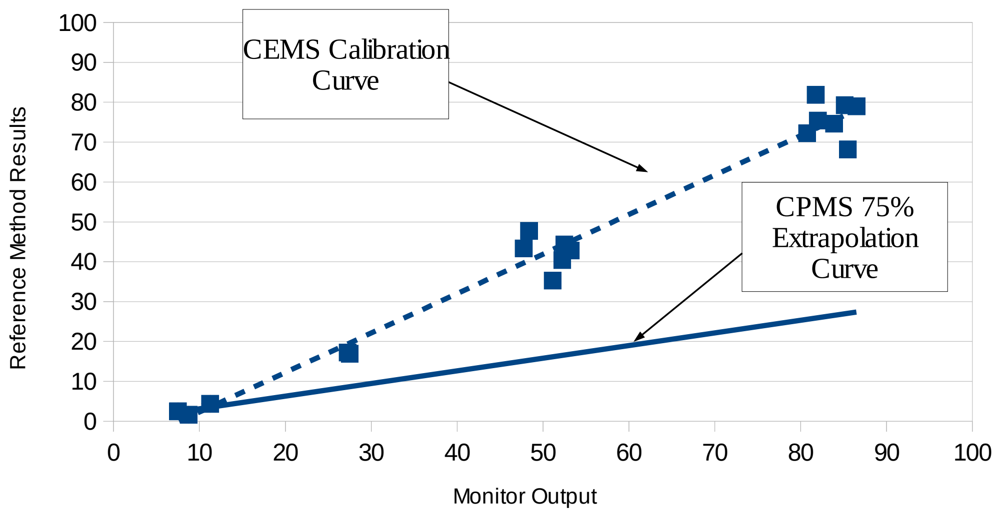


Figure 5: Example 2—Full CEMS Data set & Curve



In this data set the monitor output showed more variation than the M5 results. The resulting slope of the extrapolation line shows that the facility would never be out of compliance. When the analyzer response reaches 100% output, the facility is still less than 35% of their permitted PM limit. But again when you bring in all of the PS11 data from the entire curve, you get a different story, Figure 5.

As with Example 1, the higher PM concentration data seems to provide a better and more realistic response curve.

EXAMPLE 3

For our third example we continued to use the same approach as the previous examples. Figure 6 shows what the CPMS extrapolation curve would be for the base concentration PM. But this data set is from a facility that uses an ESP for PM control followed by a wet scrubber.

The extrapolated curve from the base PM data does not look as steep as Example 1, but it does look better.

Figure 6: Example 2—Base PM & CPMS 75% Extrapolation

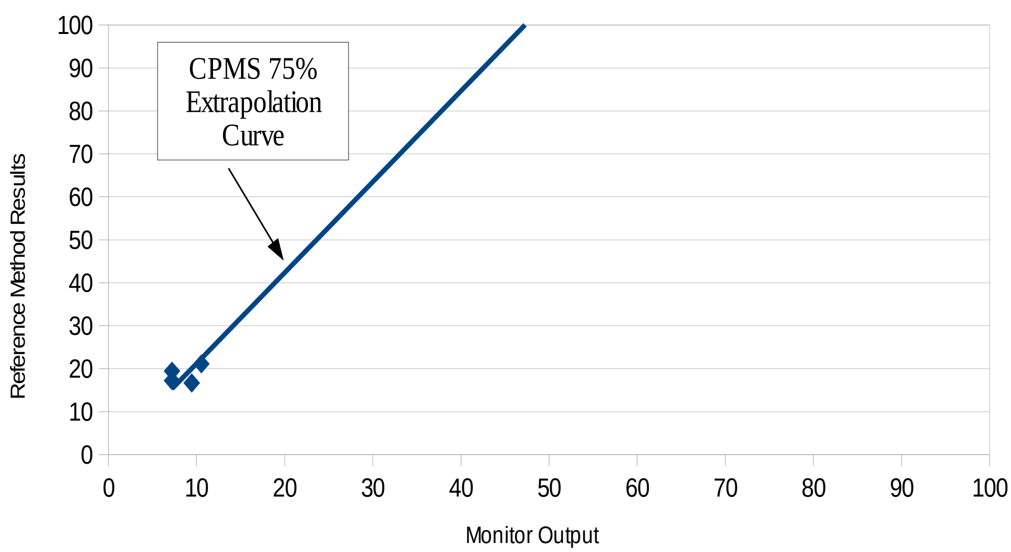
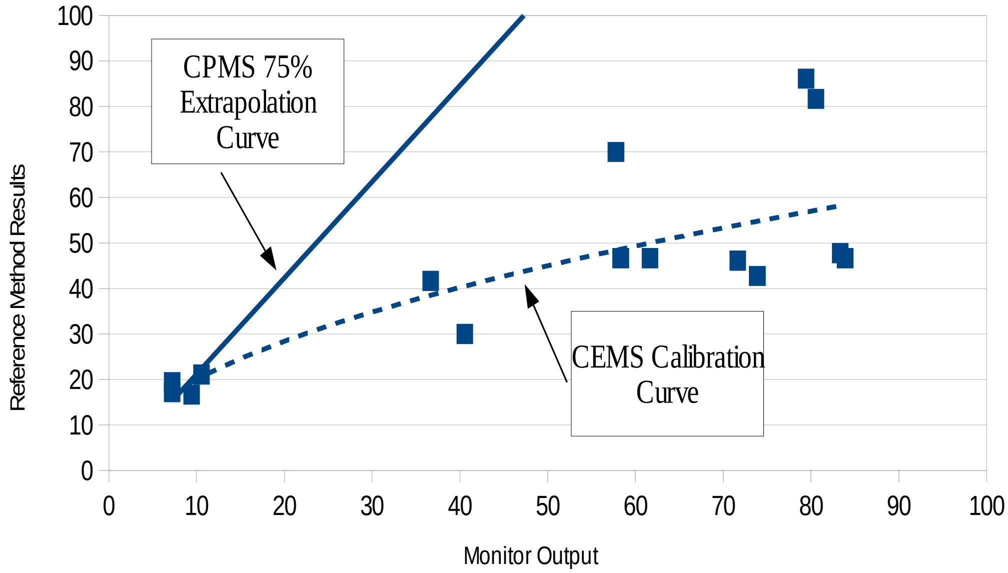


Figure 7 provides a look at the entire PS11 data set. Again the full CEMS curve provides a completely different than the extrapolated CPMS curve. In this example the higher PM concentrations also seem to provide a better overall monitor response, which seems to be the only common factor across all examples.

Of the three examples, this was the only one from a wet scrubber. This data set is important to the next sections of this paper because the PS11 data almost looks like 2 different curves, an upper curve and a lower curve.

Figure 7: Example 2—Full CEMS Data set & Curve



Due to the nature of our PM spiking service, a large majority of our experience is on systems with wet scrubbers. But we had never seen a curve result like this before. Since the testing crew was using on-site analysis, we were able to plot the results while on site. Once these trends were noticed we started to verify all of the testing conditions to look for changes. But all testing conditions were the same (e.g., gas flow rate/velocity, temperatures, PM spiking rate, etc.). The only variable that seemed to be changing was the density of the particulate being spiked.

Although the PM spiking rate was at a constant mass feed rate, B3 Systems personnel noticed that when they switch drums or dug deeper into a drum of fly ash to refill the hopper of the feeder, the motor output changed in order to maintain the same mass feed rate. We then started running periodic checks of the PM bulk density and found that it was varying from 50 lbs/cf to 85 lbs/cf, yet the material was all coming from the last field of the ESP.

Of course all of this information was being collected as the test was progressing and put together after the fact, but the changes in PM bulk density seemed to affect the monitor's output. However the M5 results were consistent with the PM spiking rate.

The on-site conclusions, while operating at a constant spiking mass feed rate, were that as the bulk density of the PM increased, the monitor's response decreased yet M5 results were consistent with the mass feed rate. Since this was not conducted as a research project, there is no hard data to support this conclusion. It should also be noted that there were slight color changes within the particulate and this was an optical instrument. However these were almost unnoticeable to the eye unless the difference materials were side by side.

THOUGHTS ON PM MONITORING

This section is based on our experience to date with PM monitoring programs and the pneumatic transport of PM. Over this time period we have worked on over 40 PM monitoring programs with all types of processes, scrubbers and stack conditions. This also includes the handling, observing and studying transport issues related to a wide variety of PM (fly ash, clinker dust, etc). The following thoughts are based on the experience gained at this point in time only, because we are constantly adding to the knowledge base.

The first thing to point out is that PM monitoring does work but it is very site specific, application specific and can be dynamic based on changes in your process conditions. It should also be noted that we have experience with many sites and applications where PM monitoring works exactly as you would expect any other monitoring to work.

The following summary will give you some items to consider as you move into or progress through your PM monitoring application. Many things can affect PM monitoring results, not all of them exist on every site. Careful planning is required from the choice of the technology to planning the testing conditions and knowing your process.

Below is a brief list of what we consider to be the key items to a successful PM monitoring program, CEMS or CPMS, or at least provides a strong basis for a successful program.

- Choose the right PM CEMS technology
- Choose a representative monitoring location
- Get a wide spread in the data for the initial curve
- Plan and Setup your testing conditions
- Document all of your testing conditions
- PM control device maintenance

The following sections will try to summary some of what we have learned in hopes you can benefit.

Choose The Right Technology

This paper will not get into any of the specifications of existing PM monitoring technologies, however we feel that choosing the right technology is a key first step in a successful program. The right technology is more than just a detector, it is an instrument that fits into a facility's structure and work flow. It is something that works with less maintenance than the other options and personnel are comfortable working on it and maintaining it. The right technology can meet the demands of the stack conditions and PM characteristics and comes with a good support team. The right technology is not driven by cost, but if everything else is equal then cost can be the tie-breaker.

In some applications several technologies may work equally as well. But the right technology is the one that your maintenance personnel are comfortable with, will maintain it and does not generate maintenance issues for them. We have worked on programs with beta attenuation, forward scatter and back scatter monitors. All of them provided great curves for the PS11 applications.

One environmental manager indicated that he was purchasing different monitoring hardware for one specific facility versus the others he was responsible for. He went on to explain that he was purchasing optical detectors at most of them because the PM was a result of the same materials being processed all of the time and the PM properties were consistent. However he was purchasing a beta attenuation unit for one facility because they processed a wide variety of materials and the processed materials had a big change on the PM properties (e.g., color, density, etc). He felt that beta attenuation technology would handle the changes in PM better than an optical technology. He went on to say that his people were very comfortable with the optical systems purchased at the other facilities because all of the maintenance and QA checks were very similar to their opacity monitors. Therefore less training was required.

Since no PM monitoring technology exists that reads mass directly on a long term basis, many of the hardware decisions are site specific.

Representative Monitoring Location

Regardless of the technology chosen, it must be placed is a location that is “representative” of overall stack concentration. If monitoring systems are being installed as part of an over construction project, get involved. There is a good chance that construction personnel do not have the experience or knowledge required to mount the PM sensor in a “representative” location.

Most people are familiar with the approach of being 8 – 10 diameters up stream of the last disturbance. This works great for velocity and pressure, but not for PM. We have studied numerous research papers on PM transport in gas streams. Every researcher documented that the velocity profile leveled out but the PM stayed close to the walls and was more a function of the velocity profiles and air flow dynamics as the gases exited the last turn or disturbance. And since no two facilities are designed or operate exactly the same, a “representative” location is very site specific.

Although B3 Systems has not taken part of locating the “representative” location, it is known that some facilities have conducted stratification testing, similar to CEMS stratification testing, to help identify the best monitoring location for the PM CEMS. In other cases good process knowledge may be more than adequate.

We should not have to say it here but we will. Just because a port is available does not make it a “representative” monitoring location.

Data Spread Is Important

A wide range in the data set used for the establishing the calibration curve or setting the alarm limit is important, especially if your normal PM is extremely low. All facilities have a cycle or noise level for every parameter in a facility. This is also true to PM emissions (e.g., baghouse cleaning vs filtering only, ESP rapping, etc). Therefore increasing the PM concentration outside the natural process variations or noise level provides better results.

Some of the areas affected by higher PM concentrations are:

- monitor response
- M5 testing & results

- retesting requirements
- data quality & QA

Monitor Response

Since a CEMS application is required to calibrate over three (3) PM concentrations, this benefit is primarily for CPMS applications. As you saw in the previous examples, getting the PM above the base conditions and into a better operating range seems to provide a better response curve.

M5 Testing & Results

Increased PM concentration helps the M5 testing and results. Higher PM concentrations can shorten the sampling run-times required and/or improve the results by allowing the M5 train to collect more PM. The more PM collected means less weighing errors in the lab.

Retesting Requirements

If a CPMS application normally operates with very low PM, this may have little affect on their retesting requirements since they can extrapolate up to 75% of their permit limit. However the retesting for a CEMS application is directly associated with the highest monitor response used in the calibration curve. So at least one high data point is beneficial to reduce the change of retesting.

Data Quality & QA

Higher PM concentrations help the monitor response and the M5 results for both CPMS and CEMS applications. But a CEMS application has additional QA checks for the initial curve as well as their RCA every third year. The initial curve of a CEMS must meet a minimum correlation requirement (> 0.85). A simple spreadsheet exercise quickly shows that you get a better correlation with a wider spread in the data. But an additional benefit is that valid data points collected for the RCA must fall within the monitors response data used to establish the initial calibration curve. Therefore extending the data set, both high and low, for the initial curve makes it easier to get valid data points for the RCA later.

Plan and Setup Testing Conditions

The title for this section is very general but it encompasses a much bigger and important part of your PM testing program. Details on this section are very site-specific and could be a short workshop within themselves. This paper will only address the broader topics of this subject. The key words to remember for this section are:

- consistency
- repeatability

These two words are very important to almost every aspect of your program. There needs to be consistency and repeatability in:

- the reference method testing
- stack gas flow
- stack gas temperature
- stack gas PM concentration

Therefore we recommend approaching this similar to a hazardous waste trial burn. Know what conditions you can obtain, hold and repeat within the process. This includes not just gas flow rate and temperature, but also PM concentration. Holding these steady normally results in a better correlation between the single point PM monitor and the reference method that traverses.

Document All Testing Conditions

With all of the above taken care of, the final piece to the puzzle is documenting all of the conditions used in setting the initial calibration curve or the alarm limit. This will be most important when it comes time to conduct the RCA on your PM CEMS or establish the PM CPMS alarm limit the following year.

PM Control Device Maintenance

After you have executed a successful testing program to generate a calibration curve or alarm limit, the most important item for staying in compliance with PM is proper maintenance of your PM control device. This paper will not attempt to address specific items, but it is easily understood that if your PM emissions are maintained at very low levels then there should not be any compliance issues.

PM Monitoring is Complicated

This document constantly refers to our experience related to PM monitoring. We think our experience is pretty diverse, but by no means does it represent a complete understanding of all of the issues surrounding PM monitoring. With each application we seem to be constantly gaining new knowledge. But the knowledge and issues related to PM monitoring can be very site specific. Therefore we would like to leave you with the following list of items that we have experienced which could affect your PM monitor and testing, depending on your specific conditions.

- Process Testing Conditions
  - Gas flow rates
  - Temperatures
  - Cleaning cycles
  - PM stratification
  - Dissolved Solids / PM
  - Changes in PM (e.g., color, density, etc)
- Stack testing
  - Probe line type
  - Clean ports

- Monitor
    - Proper output range
    - Monitoring a "Representative" location

CLOSING

This paper referenced three (3) questions in its title about PM CEMS versus PM CPMS applications:

- What are they?
- How are they Different?
- What are the Regulatory Implications of the Technologies?

Although the regulatory alarm points and initial calibration/setup is different, both applications are very similar. PM monitoring is new and requires different planning and preparation than other compliance or process monitoring applications. But the hardware for both applications is the same and the same care should be taken in planning the M5 testing no matter the number of runs.