Method 301 Study Comparing EPA Method 9 and ASTM D7520

at Encina Power Facility

Carlsbad, California

Performed By Virtual Technology, LLC.

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Contents

1.   Scope

This Method 301 study compares data gathered per EPA Method 9 with data gathered per ASTM D7520 (digital camera method) at the Encina Power Station (EPS) in Carlsbad, CA. The focus of this study is to compare the methods when utilized on fixed sources having stacks with an internal diameter greater then 7ft. The EPS Facility meets that requirement.

2.   Background

During the course of developing ASTM D7520, a consensus method for digital camera use in scenarios where EPA visible observation methods, such as Method 9, have historically been utilized; a 7 foot internal stack diameter limitation was inserted due to lack of data related directly to "Large Diameter Stacks". Albeit humans certified as Visible Emission Observers (VEO) in the same way DCOTS certify have no such "Large Diameter Stack" limitation to read Visible Emissions.

The data contained herein addresses the issue of ASTM D7520's applicability to 7ft. stacks by virtue of its statistical performance compared to EPA Method 9 (the current compliance method) in determining opacity from stacks with internal diameters greater than 7ft.

3.   General Field Procedure

A team consisting of two certified Method 9 readers, and two certified camera operators set up to read each source such that they were clustered tightly together in a place compliant with sun angle, and other Method 9 viewing related considerations. The camera date and times were synchronized. Each camera was equipped with a tripod and an intervalometer (programmable electronic shutter trigger) set to fire every 15s. Humans were equipped with Android devices running a customized field application which triggered them to read every 15s with an audible tone. It also collected all the EPA Method 9 required field data. The software can be downloaded here:

http://www.virtuallc.com/terms.asp

To start, Humans and cameras were synchronized with a countdown. Each session of data gathering was limited to an hour or less due to human fatigue. This generally produced 9 sets (two Method 9, and two cameras) of 24 readings. The images were subsequently analyzed by certified DOCS II Analyst. The comparison of DOCS II image-derived opacity against that of the Human observations is the basis for the data to be analyzed here.

4. Site Assessment and Selection

4.1 Site Assessment and Selection

To reduce travel expenses an initial limit was applied such that facilities located near Virtual Technology LLC offices in AZ, UT, CA were utilized.

4.1.1 A list of possible sites that met the industrial criteria required was compiled from State and Local Permit Databases: Coal power facilities, Natural Gas power facilities, and Cement production facilities to comply with EPA/OAQPS guidance for the 301 study.

- Each industrial facilities operating permit was reviewed to ascertain that the emission points had exits larger than 7 feet.
- Emission point configuration with respect to sun travel.
- The facility was in operation and operating under normal operating conditions.
- Facilities that met the initial criteria were added to an initial facility list.

4.1.2 Using Google Earth satellite imagery, each of the facilities surrounding geography and topology was reviewed to verify the facility had:

- Adequate observation positions offering:
  - o Sun angle compliance*
  - o Slant angle compliance*
  - o Open space out of the way of operations
  - o Minimal interferences (traffic, (pedestrian and vehicle), dust and other fugitive emissions
  - o Secure, safe and healthy conditions

4.1.3 Using DOCS II SaaS the facilities selected where located within the location tab of the software to verify:

- Sun angle compliance* (observation time window)
- Slant angle compliance* (observation position limits)

    *Per the requirements of EPA Method 9 and ASTM D7520.

To account for sun compliance and slant angle, the site needed to have large enough surrounding area where observation positions would be in both sun and slant angle compliance, while not interfering with the operations of the plant or catching other interferences such as facility traffic and/or pedestrian/freeway traffic. In addition, we reviewed each facilities' site to insure the planned observation positions were also free of interferences from other emission points, and unrelated fugitive sources.

The planned observation positions were then tested for sun and slant angle compliance for a minimum of one hour to complete the required observations, e.g. (9)* (6 minute observations) = 54 minutes. Based on the facility operating permits, we established the configuration of the emissions points, e.g. multiple flues and their orientation with respect to sun travel to insure observations could be made on single emission points without interference.

Using this methodology we selected facilities that conformed to the critical requirements. Further, facility selection was influenced by relationships with facility operators, regulatory agencies and land owners, e.g. Navajo nation.

4.2 Field Team Personnel

Personnel were selected for the study, per the following credentials:

- EPA Method 9 Certified Visible Emission Observer
- DOCS II Certified Camera Operator
- Field Visible Emission Observation Experience (1) yr.

Each 301 Field Team consisted of (2) persons meeting the credential requirement. Each member performed the following field work:

Observation Point review:

- Verify via DOCS II SaaS while physically at the planned observation points:
    - Sun angle compliance
    - Slant angle compliance (if movement possible)
    - No interferences (wires, trees, etc)
    - Current and forecasted ambient conditions
    - Adequacy of observation point given ambient conditions
    - Adjustment as needed to meet requirements

Create "C(X)"Facility" Observation record in DOCS II SaaS Mobile

- Establish camera position, (Update VEO record in DOCS II SaaS Mobile)
- Establish emission point, (Update VEO record in DOCS II SaaS Mobile)
- Establish observation point, (Update VEO record in DOCS II SaaS Mobile)
- Verify Weather conditions, (Update VEO record in DOCS II SaaS Mobile)
- Focus camera on observation point
- Verify Intervalometer set to trigger camera every 15 seconds from start
- Save/exit "C(X)"Facility" DOCS II SaaS Mobile VEO record"

Create "M(X)"Facility" Observation record in DOCS II SaaS Mobile

- Establish Observer position, (Update VEO record in DOCS II SaaS Mobile)
- Establish emission point, (Update VEO record in DOCS II SaaS Mobile)

- Establish observation point, (Update VEO record in DOCS II SaaS Mobile)
- Verify Weather conditions, (Update VEO record in DOCS II SaaS Mobile)
- Begin recording VEO readings in (DOCS II SaaS Mobile Manual Entry Mode)
    - Simultaneously start camera intervalometer with initial VEO reading entry
    - Record VEO readings every 15 seconds for 60 minutes (240 readings).
    - Turn off camera intervalometer at conclusion of VEO readings
- Save DOCS II SaaS Mobile Manual Entry record and upload to cloud server
- Access DOCS II SaaS Cloud and finalize (archive) "M(X)"Facility" VEO record

Open "C(X)"Facility" Observation record in DOCS II SaaS Mobile

- Open WiFi connect and Transfer Images from the Camera to the Mobile device.
- Attach Images to C(X)"Facility" CEO record, and upload to the cloud
- Access DOCS II SaaS Cloud and open "C(X)"Facility" CEO record, enter emission description and submit for Analysis

4.3 Schedule

301 Field Teams established 2 day windows of availability and, the planned observation positions were reviewed for forecasted weather conditions based on execution window dates. Every attempt was made to capture a variety of weather backgrounds for the study. However, given the summer season in the western United States sunny and hot seemed to be the prevailing weather condition experienced.

301 Field Teams traveled to the facility, and verified the planned observation points per the criteria. When the site pre-planning was correct and adequate time during the sun compliance window existed the field data collection was performed.

If the 301 Field Team did not have an adequate time window at that time, (travel time exceeded plan) then the Team returned the next day during the required time window.

VT LLC acknowledges the help and assistance of SRP, USEPA Region 5, Duke Energy, The Navajo Nation, AZ DEQ, CEMEX Rillito AZ, Pima County Health, Rocky Mountain Power, Carbon County Health, UT DEQ, CEMEX Mohave, Mohave Air Quality Management District,

4.4 Photo Analysis:

Analysis of the 301 Field Team imagery, was performed by Analyst with the following credentials:

- DOCS II Analyst Certification
- DOCS II Camera Operator Certification
- 1 year Field Experience with DOCS II SaaS Analysis Engine

Analyst Team:

Each 301 Analysis Team consisted of (2) Analyst meeting the required credentials, and residing in different VT LLC offices to insure maximum independence. Each 301 Analyst member performed the following as independently as possible:

- Receive DOCS II SaaS email notifying that a 301 Field Team C(X)"Facility" CEO is ready for Analysis.
- Open C(X)"Facility: CEO record in DOCS II SaaS
- Verify information on, Properties, Source, Plume, Location, (Tabs)
- Open Analysis Tab, Set Total Average Rule
- Review all 240+ Images are received and loaded
- Mark Foreground, Region of Interest (ROI) at point on plume with highest apparent opacity
- Mark Background ROI at point of best contrast outside the plume in the image, as close to the same horizontal plane as the Foreground ROI as possible.
- Run automatic to copy the positioned ROI across all images
- Review each image to insure ROI's are in acceptable position given wind drift, light intensity and shadowing.
- Send C(X)"Facility" CEO record to Quality Assurance

301 Source Record QA

Quality Assurance of the 301 Analysis and Field CEO records was performed by personnel meeting the following required credentials:

- DOCS II SaaS QA Certified
- DOCS II SaaS Analysis Certified
- DOCS II SaaS Camera Operator Certified
- 1 year Field Experience performing QA on DOCS II SaaS observation records

4.5 Source Record QA Team

Each 301 Source Record QA Team consisted of (2) QA Analyst meeting the required credentials, and residing in different VT LLC offices to insure maximum independence. Each 301 Analyst member performed the following as independently as possible:

Receive DOCS II SaaS email notifying that a 301 C(X)"Facility" CEO is ready for Quality Assurance.

- Open C(X)"Facility: VEO record in DOCS II SaaS
- Verify information on, Properties, Source, Plume, Location, (Tabs)
- Open Analysis Tab, verify Total Average Rule selected
- Review all Images, verify ROI positioned in accordance with training
- Run Draft C(X)"Facility" VEO record report verify contents
- Run Final C(X)'Facility" VEO report to archive and lock the record.
- Contact 301 Field Team to validate the M(X)"Facility" VEO records are final, locked and ready for extraction (note Manual Entry VEO's can only be viewed and manipulated to final locked status by the originating Field user, e.g. the person who entered the opacity values.

4.6 Data Reduction

Data Reduction of the 301 Finalized set of C(X)"Facility" CEO records and M(X)"Facility" VEO records was performed by personnel meeting the following required credentials:

- 10 years statistics in Excel experience
- DOCS II SaaS QA Certified

Upon finalization of C(X)'Facility" CEO records the 301 Data Reduction personnel are notified by the 301 Source Record QA Team members that the source data is final, locked and ready for data reduction to be performed. The 301 Data Reduction person then instructs the 301 Source Data QA person to export the C(X)"Facility" records into their designated cloud library as Excel files. The 301 Data Reduction person then notifies the 301 Field Team to export the corresponding M(X)"Facility" VEO records into the same designated cloud library as Excel files. The individual Excel files are then combined by the 301 Data Reduction person, meeting the required credentials, into "301" template spreadsheets that were prepared during the discussions with the EPA/OAQPS Alternative Methods personnel to insure the proper calculations were being performed on sample sets of data independent of the data collected by the 301 Field Team. In effect the Data Reduction person established the procedure for Data Collection referenced in 301 Field Team Execution section above.

Once the 301 M(X)"Facility" VEO and C(X)"Facility" CEO records are combined into the 301 Data Reduction Spreadsheet(s) each tab of M(X)"Facility" and C(X)"Facility" source data is visually compared with the originating source to insure error free data reductions.

The 301 Data Reduction Spreadsheet(s) calculate the critical values for Precision and Bias in accordance with Paragraph 5 of this document.

Once complete the Data Reduction personnel notify the publication personnel that the 301 Data Reduction is complete the graphics are generated and ready for publication.

4.7 Publication Team

The 301 Publication people are required to have the following credentials:

- 5 years Power Point Experience
- DOCS II SaaS Camera Operator Certification

The 301 Publication personnel, creates a 301 PowerPoint Template file to import data directly from the 301 Data Reduction Spreadsheet(s). 301 Publication personnel with the required credentials perform the following steps to produce the publication graphics for a DOCS II SaaS, to EPA Method 9, 301 Comparison Study Poster:

- Load 301 PowerPoint Template.

- Import graphics from Data Reduction Spreadsheets into 301 PowerPoint Template.
- View Locked C(X)'Facility" records in DOCS II SaaS and Publish the Locked Records to JPG.
- Crop Required Properties and Location information into individual JPG files and import into the 301 PowerPoint Template.
- Contact the 301 Field Team and have them View the Locked M(X)"Facility" VEO records, and Publish the Locked Records to JPG, to the designated cloud library.
- Crop Required Properties and Location information into individual JPG files and import into the 301 PowerPoint Template.
- Update 301 PowerPoint Template to insure fit and presentation quality of the Poster.
- Render the poster at scale to perform final review.
- Update as required to verify Poster Publication Integrity
- Generate Final PDF version of 301 Study XXX, and send to printing services.

5.   Analysis

This 301 study is a comparison of an alternative method, ASTM D7520 to an existing method, EPA Method 9, by way of Quadruplet sampling. No analyte spiking or Isotopic sampling treatments are applicable. In addition, since the samples are recorded observations from humans, and captured imagery from a digital camera, no sample shelf life issues are considered, i.e. no concerns for sample stability, thus associated calculations were not performed.

The NIST traceability to the reference is achieved by utilizing human EPA Method 9 certified smoke readers who certified on smoke generators whose calibration was performed via NIST traceable filters.

Attached to this document is a spreadsheet " ENCINA 301 Data" containing two tabs. The first Tab is called "ENCINAs" and contains the statistical analysis associated with this study. The second Tab is called "ENCINAd" and it contains the Observed field data and DOCSII analysis associated with this study.

Referring to the spreadsheet, tab "ENCINAd" the column headings are defined as:

1) Set - refers to a 6 minute block consisting of 24 readings (0-23).

2) Time (Sec) - refers to the relative time in the set each human observation or picture was taken.

3) Camera a - refers to the first camera, and contains the specific file names of the images captured and subsequently analyzed by DOCS II. The "a" designation allows for easy identification of camera-Method9 -DOCS II analysis which belong together, i.e. camera a images were analyzed and the results are in DOCS II-a, and are matched to M9a for statistical comparison, etc.

4) Camera b - refers to the second camera, and contains the specific file names of the images captured and subsequently analyzed by DOCS II.

5) M9a - refers to the first human Method 9 reader

6) M9b - refers to the second human Method 9 reader.

7) DOCS II-a - refers to the results of DOCS II analysis for the corresponding image identified in the camera a column.

8) DOCS II-b - refers to the results of DOCS II analysis for the corresponding image identified in the camera b column.

The formulas utilized in the calculations can be seen in the accompanying spreadsheet, as well as the results of the analysis as expressed by precision and bias. The procedure and analysis used follows.

5.1 Bias

Referring to the spreadsheet tab "ENCINAs", the column headings are defined as:

Validated Method Observations – refers to the grouping of data related to EPA Method 9 observations.

 M9a – Data recorded by the first M9 Observer.

 M9b - Data recorded by the second M9 Observer.

 $(V1_i + V2_i)/2$ – Average of the ith sample of M9a and M9b Observation.

 Variance Mv – Variance associate with M9a and M9b observations.

Alternate Method Observations – refers to the grouping of data related to DCOT observations and analysis.

 DOCSIIa – Data recorded by the first DOCSI Observer/Analyst.

 DOCSIIb - Data recorded by the second DOCSII Observer/Analyst.

 $(P1_i + P2_i)/2$ – Average of the ith sample of DOCSIIa and DOCSIIb Observation.

 Variance Mp – Variance associate with DOCSIIa and DOCSIIb observations.

Comparative Statistics – refers to the statistical analysis performed to generate Precision and Bias.

 d_i – difference between "$(V1_i + V2_i)/2$" and "$(P1_i + P2_i)/2$"

 $(d_i-d_m)\text{^}2$ – Individual di values less the mean of all di (which is d_m)

 T test – Calculation that determines the bias associated with the method.

 F test - Calculation that determines the bias associated with the method.

Paragraph 11.1 of Method 301 dictates that we must test bias for statistical significance at the 95% confidence level by calculating the T statistic. In order to determine statistical significance, mathematical bias and standard deviation must be derived.

1) Mathematical Bias (mean of the differences between methods) is determined via the following equation:

$$d_i = \frac{(V_{1i} + V_{2i})}{2} - \frac{(P_{1i} + P_{2i})}{2}$$

Where:

V_{1i} = First measured value in the validated method sample pair.

V_{2i} = Second measured value in the validated method sample pair.

P_{1i} = First measured value in the alternative method sample pair.

P_{2i} = Second measured value in the alternative method sample pair.

2) The Standard Deviation is determined via the following equation:

$$SD_d = \sqrt{\frac{\sum_i^n (d_i - d_m)^2}{n-1}}$$

Where:

d_i = Difference between results of the ith sample (min -max).

d_m = The mean of the paired sample differences.

n = total number of paired samples

3) Procedure and calculation for determining Bias results:

The t value is determined by using the following equation:

$$t = \frac{|d_m|}{\dfrac{SD_d}{\sqrt{n}}}$$

Where:

d_m = Mathematical Bias (calculated in item 1)

SD$_d$ = Standard Deviation (calculated in item 2)

n = total number of paired samples

Once the t value is derived, it is compared to a value from a reference table (Table 1, Method 301). The value from the reference table depends on the degrees of freedom and confidence limit. While Quadruplet replicate systems can utilize as few as 4 samples, this study utilized 9, thus the reference table critical t value would be 2.306. (9 degrees of freedom). If the calculated t value is less than the critical value, the bias is not statistically significant. In this case It was not significant.

5.2 Precision

Paragraph 11.2 of Method 301 dictates that we must test precision for statistical significance at the 95% confidence level by calculating the F statistic. In order to determine statistical significance, variance for the validated and alternative methods must be derived.

1) Variance for the alternative method is determined via the following equation:

$$S_p^2 = \frac{\sum_i^n d_i^2}{2n}$$

Where:

di = difference between the ith pair of samples collected using the alternative method

n = total number of paired samples

2) Variance for the validated method is determined as is done for the alternative method above.

3) Procedure and calculation for determining Precision results:

The F value is determined by using the following equation:

$$F = \frac{S_p^2}{S_v^2}$$

Where:

S^2_P = Estimated variance of the alternative method

S^2_v = Estimated variance of the validated method

Once the F value is derived, it is compared to a value from a reference table, which can be found online . The value from the reference table depends on the degrees of freedom (paired sample size) and confidence limit. While Quadruplet replicate systems can utilize as few as 4 samples, this study utilized 9, thus the reference table critical F value would be 3.18. (9 degrees of freedom). If the calculated F value is less than the critical value, the difference in precision is not statistically significant.

6.   Results

Our study of the Encina data shows no appreciable difference between these two methods. The critical value for bias is 2.306. The Encina results bias at 1.18. The Critical value for Precision is 3.18. The Encina results showed precision of 2.36.

7.   Conclusion

DOCS II and Method 9 are interchangeable at 0-5% opacity, regardless of stack diameter.