An Evaluation of a Digital Camera System for Measuring Smoke Plume Opacity

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Presentation Topics

• Why we should be interested in camera methods for measuring smoke plume opacity.
• The Digital Opacity Compliance System, version II (DOCS II).
  – How it works
  – DEQ results
• How to overcome some of the limitations of Complex Analyses in DOCS II.
• Summary and next steps.
Why should we be interested in camera methods…

- Digital camera methods can eventually be more accurate than Method 9.
- Pictures document visible emission violations well & provide excellent evidence.
- Visible emission evaluations are frequently performed – it is a common test and it should be a good one.
Why should we be interested in camera methods...

• Time and cost savings
  – Camera methods could potentially lower staff training time and costs by avoiding Method 9 certification training.
  • At the DEQ, instead of certifying 47 staff to perform Method 9.
  • DEQ could train inspectors to take pictures and have them forward the pictures to a regional office or contractor for analysis.
Why should we be interested in camera methods...

- Method 9 is often poorly performed by facilities and contractors

Zero percent opacity? The Method 9 contractor thought so...
Why should we be interested in camera methods...

- Young tech-savvy staff can’t believe we are still using an old visible method....

Dude, this Method 9 is so retro ‘70s! You got an app for my phone?
Why should we be interested in camera methods…

• All air agencies should be interested in camera methods because of:
  – All the reasons previously discussed.
  – National time and cost savings:
    • State and local agencies spend about $885,000 per year on certifying their staff to perform Method 9. ¹
    • The regulated community (government & industry) also spends considerable time and money performing Method 9.
  – A quick and easy, accurate method of determining stack opacity would save everyone time and money.

¹ NACAA annual cost estimate does not include travel and lodging costs.
Digital Opacity Compliance System, Version II (DOCS II)
DOCS II

• DOCS II is a commercial product that uses:
  – a digital camera,
  – software, and
  – a trained user

to measure smoke plume opacity.
DOCS II

• DOCS II is sold by Virtual Technology LLC. See: http://www.virtuallc.com/

• Contact Person: Shawn Dolan, President of Virtual Technology, LLC:
  – shawn.dolan@virtuallc.com
  – (888) 872-3836

• Cost: About $5,495

• Virtual Technology offered DEQ a free trial of the system in September 2011.
The Camera

• Canon PowerShot G11 (a Nikon camera is also available).

• To comply with EPA Alternative Method 82:
  – The camera was operated in:
    • Default auto focus mode
    • Default auto exposure mode
  – The camera generated EXIF 2.1 JPG (or higher) output files.
  – Optical zoom on.
  – Digital zoom off.

EXIF = Exchangeable Image File Format
Photographing the Plume

- Position yourself as you would for Method 9.
- Position yourself to maximize the contrast between the plume and its background.
- Turn off digital camera features such as: flash, optical filters, digital zoom, image stabilization.
- Do not photograph steam....
- Center pictures on the plume observation point.
- Take JPEG images every 15 seconds.
Analyzing the Photographs

• Download the photographs to a PC.
• Exclude photographs that should not be used.
• Analyze the photographs with software.
  – Compare “in the plume” areas to “background” areas adjacent to the plume.
  – The difference between “in the plume” values and “out of the plume” values is correlated to opacity.
• DOCS II offers two options: Simple or Complex Analysis Modes
Simple vs. Complex Analysis

• Simple Analysis:
  – Use Simple Analysis for homogenous backgrounds (but not gray backgrounds).
  – Example: black or white smoke on blue sky.

• Complex Analysis:
  – Use Complex Analysis on heterogeneous backgrounds and gray backgrounds.
  – Examples: forest or gray sky backgrounds.
Analyzing a Series of Photographs in Simple Analysis Mode

In plume data

Background data
Some Simple Analysis Results

Baltimore ETA Smoke School, November 2, 2011, Run #1, Black Smoke on Blue Sky, P. Thaler Analyst

\[ y = 1.065x - 6.8292 \]
\[ R^2 = 0.9905 \]
Some Simple Analysis Results

Baltimore ETA Smoke School, November 2, 2011
Run #2, White Smoke on Blue Sky, P. Thaler Analyst

y = 0.8905x + 7.4222
$R^2 = 0.9735$
Some Simple Analysis Results

Pohick Bay ETA Smoke School, April 5, 2012, Run #6, Black Smoke on Blue Sky, P. Thaler Analyst

\[ y = 1.065x - 6.8292 \]

\[ R^2 = 0.9905 \]
Analyzing a Series of Photographs in Complex Mode

• Select a zero opacity image.
• Use the zero image as your background photo.
• Place your “in plume” and “out of plume” sticks (boxes) on the background image until you get a green or yellow light to proceed.
• Superimpose the zero opacity/background image on each photo in your series of photos.
• Click “Accept the Boxes” on each photo.
• The software estimates the opacity.
Analyzing a Background Image in Complex Analysis Mode

In plume “sticks” or box

Colored indicator boxes

Background “sticks” or box
Superimposing a Background Image on a Photograph in Complex Mode

Image being analyzed
Complex Mode Problems

• The No Zero Image Problem
  – In the real field work, zero images may not be available.

• The “Getting the Green Light” Problem
  – Getting a “green light” to accept your stick placement on a zero opacity image is difficult & time consuming.

• The Superimposing Images Problem

• The Erroneous Opacity Problem
  – Even when the software gave us a green or yellow light to proceed, the software often produced erroneous opacities in Complex Mode.
Some Complex Analysis Results

Baltimore ETA Smoke School, November 2, 2011
Run #1, White Smoke Tree Background, P. Thaler

DOCSII vs ETA

One-to-One Line
Complex Mode Solutions

• Determine if a zero image is really needed.
  – Our preliminary work indicates a zero image may not be necessary.

• Calculate the average Red, Green, Blue (RGB) values in the plume and in the background using imaging software like ImageJ.

• Subtract the RGB values.

• Plot the difference.
Pohick Bay ETA Smoke School, October 3, 2012
White Smoke, Complex Background, RGB Difference vs. Opacity

Red Difference
\[ y = -0.0086x^2 + 2.2174x + 19.221 \]
\[ R^2 = 0.9843 \]

Green Difference
\[ y = 37.677 \ln(x) - 21.365 \]
\[ R^2 = 0.9831 \]

Blue Difference
\[ y = 30.45 \ln(x) + 52.98 \]
\[ R^2 = 0.9037 \]
Complex Mode Solutions

• Automate the “Getting the Green Light” Problem
  – If a zero image is necessary, have the software find the “sweet spots” (best locations) for placing your sticks/boxes on the zero image.

• Automate the superimposing of images
  – Have the software register/align the background image to the photo under analysis.

• If all the above are done, the Erroneous Opacity Problem will likely go away…
Some Other Suggestions for Improved Performance

• Use better cameras that have:
  – Telephoto and greater optical zoom capability.
  – Explore whether manual focus and manual exposure control improve the accuracy of opacity measurements.

• Take more pictures than one every 15 seconds.
  – Averaging four or more pictures every 15 seconds might improve accuracy.
  – Would videos of smoke emissions improve performance?
The California Experience with DOCS II

• Al Arnone runs smoke schools for the California Air Resources Board (CARB).

• Al reports:
  – He has used DOCS II at about 14 smoke schools and likes the product.
  – He is certified to perform EPA Alt. 082, but he is not analyzing the photos he takes.
  – He sends his photos to Virtual Technology for analysis.

• This “send your photos out for analysis” is VT’s new Software as a Service (SaaS) sales model.
The Software as a Service Concept

Field inspector takes photos and sends them to a central location via cell phone.

Central location or contractor analyzes the photos and determines opacities observed.
Evaluation Summary

• DOCS II in Simple Analysis Mode was:
  – Easy to use.
  – Produced reasonably accurate results similar to a Method 9 reader.
  – More field trials should be conducted.

• DOCS II in Complex Analysis Mode was:
  – Difficult and labor intensive to use.
  – Often produced inaccurate opacities.

• The Software as a Service (SaaS) model might be OK if VT can clearly demonstrate the software works in Complex Analysis Mode.
Next Steps

• Funding is needed to further develop DOCS II and other systems.
• Funding could come from EPA or State & Local, Supplemental Environmental Projects (SEPs)
• NACAA members could offer funding for further development.
• More state and local agencies need to be involved in the development and evaluation of digital camera methods.

NACAA is the National Association of Clean Air Agencies
The thought I want to leave you with is:

Digital camera methods hold enormous promise as good, objective methods for evaluating smoke opacity....
Disclaimer

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