

OPACITY - CONVERTING A COMPLIANCE BURDEN TO AN OPERATIONAL COST SAVINGS

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HISTORY OF OPACITY

In 1970 the US EPA was formed based on the passage of the original Clean Air Act (CAA). The very first monitoring requirement under this act was the requirement to monitor smoke/dust by a means known as *opacity*. There has never been a finitely defined measurement application in the history of the Act.

In 1990 the US congress passed the Clean Air Act Amendment (CAAA). The purpose being to reduce the pollutant output of major sources. This, primarily effecting the utility industry for SO₂, NO_x and particulate/opacity output.

Over the years, opacity has been perceived as a regulatory burden, forced on industry only to impose government control over their operations. However, the past few years, opacity monitor manufacturers have been working with industry to help provide process payback programs for various applications. Direct participation with process equipment suppliers, such as Electrostatic Precipitator (ESP) and gas turbine manufactures have started programs for optimization of transformer/rectifier control and fuel lean-out programs.

In addition, SO₃ has become an issue for visible emissions due to the yellow/brown plume that it creates; feedback from optical devices can be used to control operating temperature. The result of such work is optimization of a process with the use of a compliance device. For once, a perceived government burden has resulted in a industry cost savings application.

THEORY OF OPERATION
(General)

OPERATION

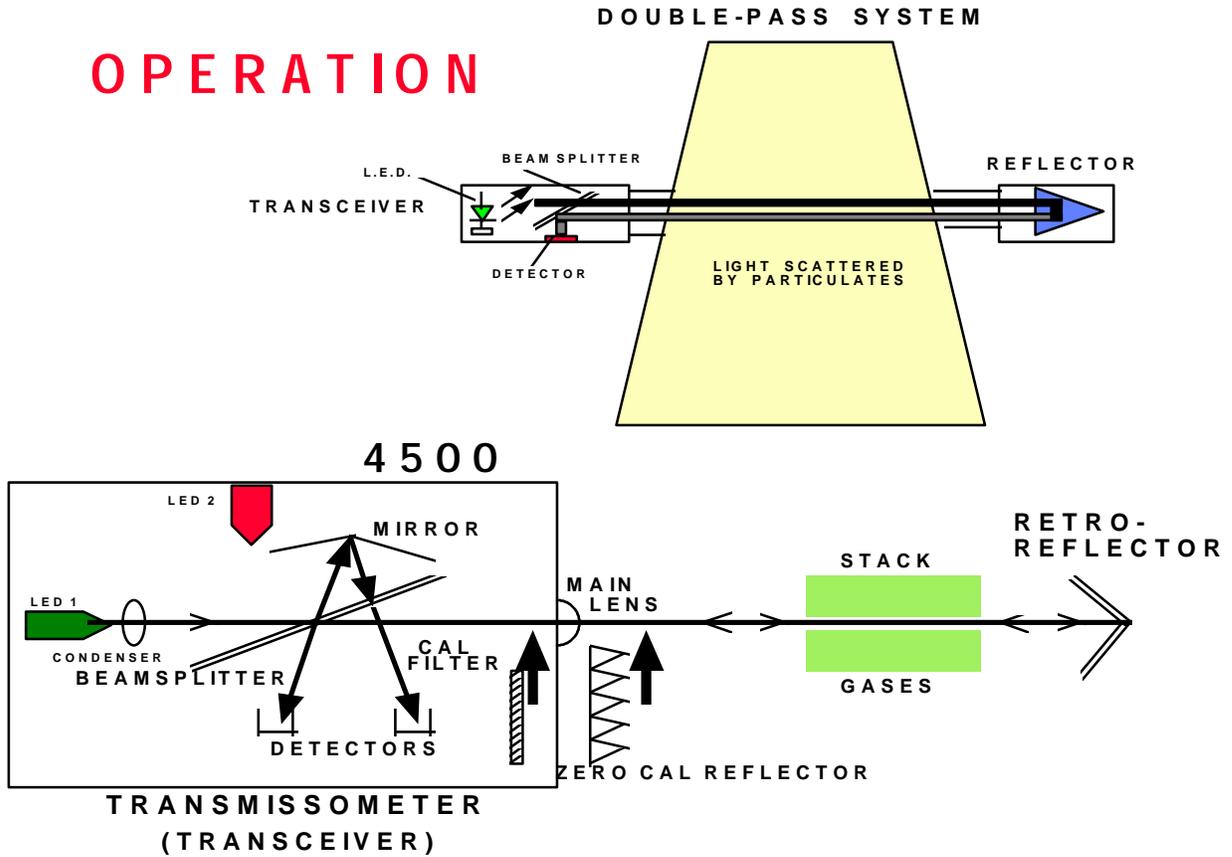


FIGURE #1

Referencing Figure #1. When a beam of light crosses a medium containing smoke or dust particles, some of the light is transmitted and some is lost due to scattering. The fraction which is transmitted is called the transmittance and the fraction which is lost is the opacity.

In the early days of emissions measurements, the opacity of the smoke leaving a stack was measured by the Ringelmann method in which a trained observer made a visual estimate of its appearance, referencing Figure #2. Even to this day, the opacity monitor is certified by a trained "smoke reader" to verify the instrument under the guidelines of 40 CFR Part 60, Appendix A, Reference Method 9.

RINGELMANN TRADITIONAL VISUAL SCALE

- Ringelmann 0 - 0% opacity (clear)
- Ringelmann 1 - 20% opacity
- Ringelmann 2 - 40% opacity
- Ringelmann 3 - 60% opacity
- Ringelmann 4 - 80% opacity
- Ringelmann 5 - 100% opacity (black)



FIGURE #2

Modern methods for opacity measurement are far more sophisticated than the Ringelmann method, but many of the specifications relate back to the way the human eye (albeit: Method 9) sees smoke emissions. In particular, the wavelength response of an opacity monitor must mimic that of the human eye; the instrument must have a nearly photopic response. At the onset of opacity monitor development, a broad band light source (white light) was used with narrow band pass filters before the detector to discriminate the light spectrum from 500-600nm (green or near-green light). Over the years, with the development of solid state technology, new techniques have been developed to use narrow band light sources (LEDs) to eliminate the need for filters and other components. Reference Figure # 3.

GREEN L.E.D.LIGHT SOURCE

TECHNICAL DESCRIPTION

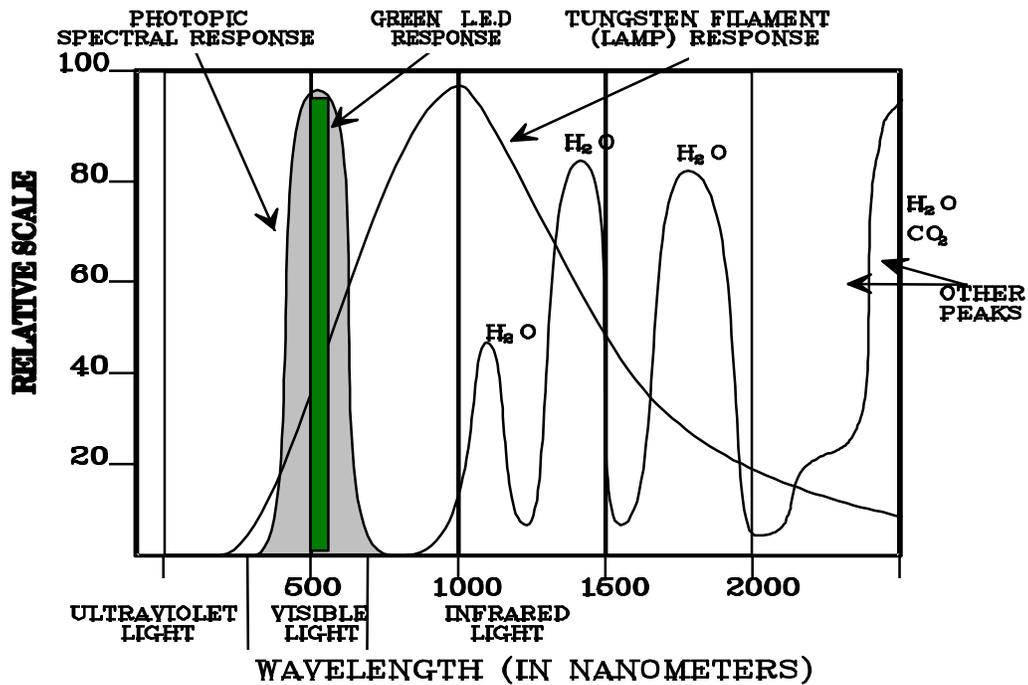


FIGURE #3

THEORY OF OPERATION
(Relation between D-value and Mass Concentrations)

OVERVIEW
UNDERSTANDING
DUST / OPACITY
RELATIONSHIPS

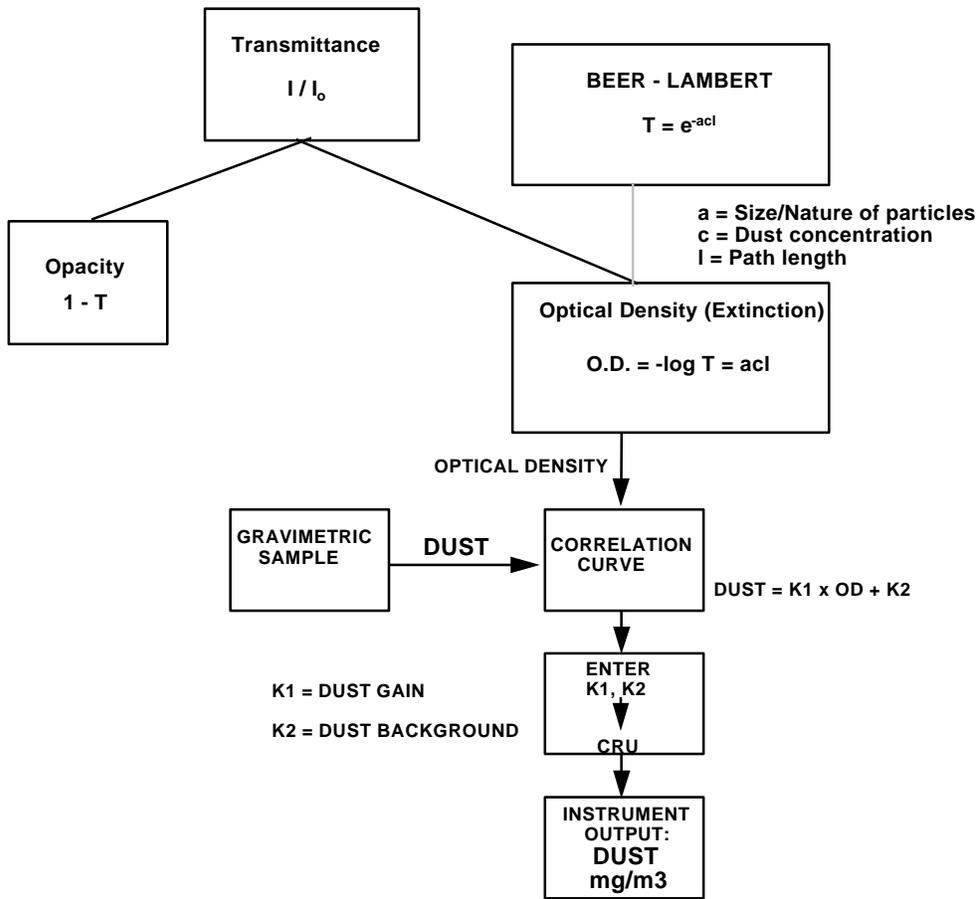
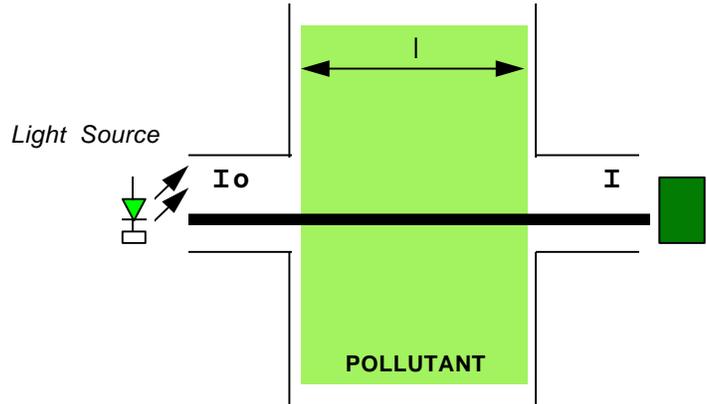


FIGURE #4

When a monochromatic light beam, such as a LED light beam, traverses through gas containing particulate matter and color, the intensity of the beam will decrease by absorption and scattering processes within the particulate distribution. The net effect can be described by the Lambert-Beer law as:

$$T=e^{-acl}$$

$$T=I/I_0$$

where

T	is Transmittance
I _o	is the source intensity of source light
I	is the measured intensity at the detector
l	is the length of the beam passage in particulate distribution
c	is dust concentration
a	is size/nature of particles

Another concept, useful in this connection, is the optical density, O.D. The D-value is defined as:

$$O.D.=-\log T=acl$$

where I and I_o are defined as earlier. It is to be noted that D-value is of general nature and has no dependence on measurement length or particulate properties. To account for many different applications and measurement setups, the D-value as solved from above, is the basic quantity for an opacity monitor. Thus the indicator range is scaled in D- values and optical filters with known D-values are readily available to check the proper operation of the instrument.

Normally the user is more interested in dust or particulate concentration in terms of mass concentration (mg/m³) or opacity (%) than D-values. The main problem for a given measurement set-up is then to express the measured D-value as mass concentration. The most reliable method to do this, is the calibration by simultaneous gravimetric sampling and D-value measuring in different particulate concentrations likely to appear in practice. Once the relation between mg/m³ and D-values is established, the problem is solved.

It is also possible to theoretically develop the above equations together with simple model of particulate distribution. The results agree extremely well to real, measured dust concentrations and gives valuable information for applicability of monochromatic light dust measurement.

APPLICATIONS

The CAA, as originally written, addressed major sources such as utilities, pulp and paper, and industrial boilers. With the onset of the CAAA in 1990, utilities were forced to look for alternative fuels and scrubbers for the reduction in SO₂ outputs. This meant higher fuel costs along with spiraling equipment costs. As we move further into the 90's lower and lower emission outputs levels are required to be met, thus forcing new technologies to be developed.

MgO Injection

As an alternative to additional pollution equipment, fuel additive companies have developed additives (magnesium-oxides, MgO) to precipitate out the SO₂ and reduce emissions. However, there is a fine line to using these additives, primarily due to cost. The additives in the fuel can vary the sulfur acid dewpoint of the exhaust gases, in affect, raising the acid dewpoint and creating sulfur-trioxide (SO₃) as an result. This has two major implications that have a direct effect with opacity readings.

SO₃ appears as a yellowish haze in the exhaust gas. The problem with this is that it is detectable in the 500-600nm spectral area, i.e., SO₃ will be detected as opacity. The negative part of this is that color is not defined as opacity and is not read during a Method 9 test. All this means is that the user can result in a higher opacity reading off of the instrument than what needs to be reported.

With the knowledge that SO₃ has color that affects opacity readings, this can be used as a positive feedback to the additive control system, as well as to the boiler control system. This signal indicates when the boiler operating temperature is too low and SO₃ is being generated, thus boiler operating temperature must be increased.

SO₃ Injection to Improve ESP Efficiency

A second application that has become very prominent is direct SO₃ injection into the inlet of the electrostatic precipitator (ESP). The injection of SO₃ into the flue gas immediately prior to the precipitator changes the resistivity of the existing particles and enhances the performance of the ESP. When the ash is over saturated, the process gas has higher levels of free SO₃, which create a higher acid dewpoint temperature, and hence, a higher probability of cold end corrosion as well as free SO₃ into the atmosphere. If there is too little SO₃, the ESP performance will suffer and more particles will be emitted into the atmosphere.

MULTI-DUCT APPLICATION

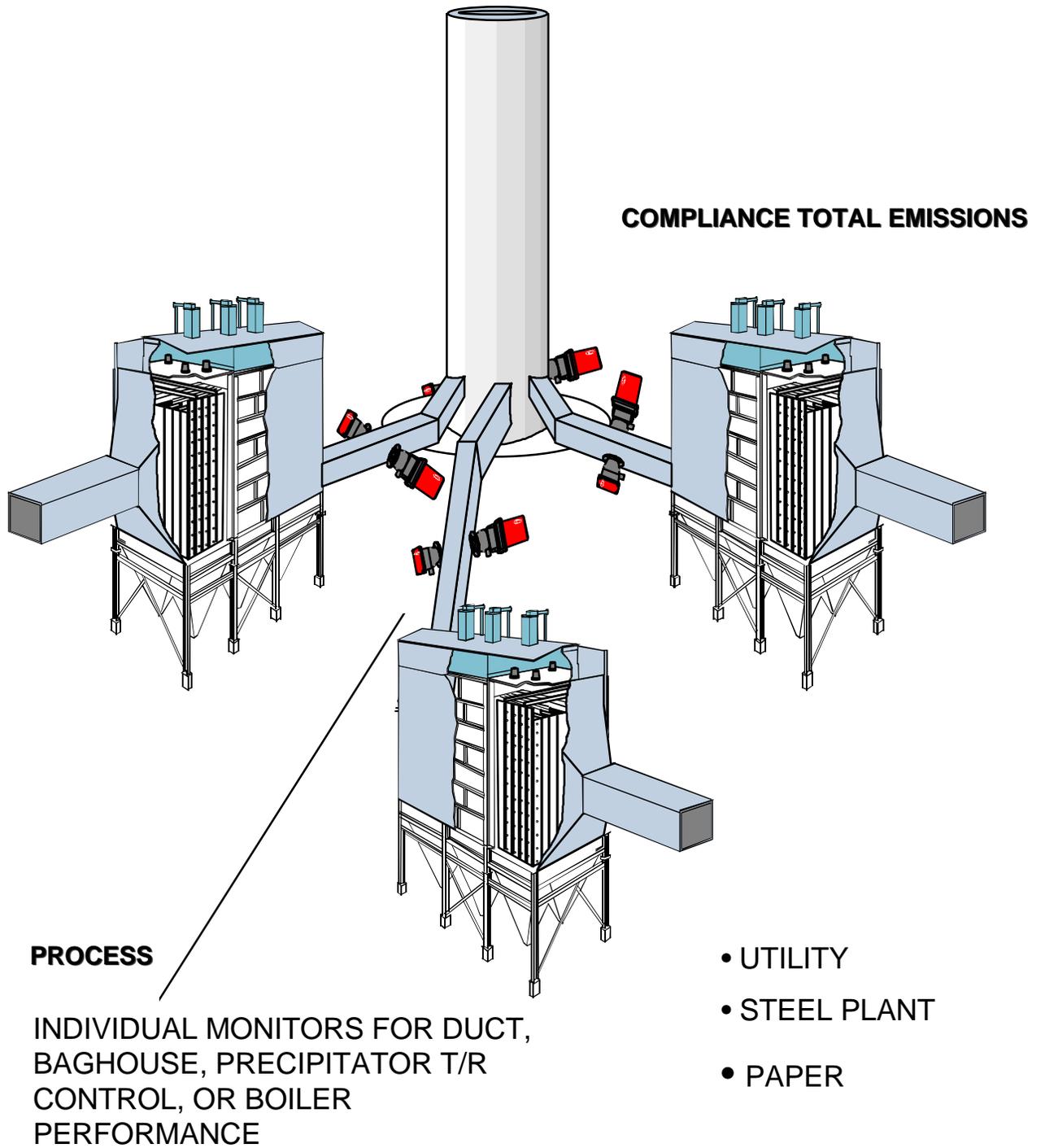


FIGURE #5

In general, most ESPs have a compliance opacity monitor on the stack for compliance requirements. Opacity becomes a "process instrument" when used as an ESP performance monitor. This is simply a matter of controlling all ESP parameters, i.e.: Transformer/Rectifier (T/R) voltage control, ESP temperature, and SO₃ injection rate. It is all a function of the output opacity value. Following are the major items that can change the opacity levels of the ESP:

1. low voltage on T/R - reduced dust collection/increase opacity
2. high voltage on T/R - creates NO₂ (brown gas) visible emission as opacity
3. low SO₃ injection - reduced dust collection/increased opacity
4. high SO₃ injection - free SO₃ (yellow gas) visible emission as opacity

This appears to be a straightforward opacity monitoring application as defined in the previous example, and so it is, provided it is a single ESP to a single stack. However, referencing Figure #5, when there is a single stack and multiple ESP inputs, the factors start to change.

Just assuming that the example shown has three equal sized ESPs then the actual value of the opacity from the single compliance unit on the stack is the sum of all the emitted material from all the ESPs. In other words, each box is approximately equal to 1/3 the total opacity value. This is the case if all ESPs are performing identical, however, the chances of three ESPs performing identical is truly unlikely. Thus the use of one compliance opacity monitor on the stack to control multiple ESPs creates a condition where all ESPs are being controlled by the least efficient ESP. This creates a higher operating cost to the user in power and additives.

The best scenario for the user is to install "process opacity monitors" at the outlet of each ESP (reference Figure #5). By installing a monitoring device at the outlet and reading the opacity value at that point, not corrected to the stack exit value, the user can optimize each individual ESP for its own maximum performance. The benefits of this control concept is as follows:

1. minimize stack opacity output
2. optimize additive consumption
3. maximize dust removal
4. minimize power usage
5. optimize ESP performance
6. reduce operating costs

SUMMARY

The use of opacity monitoring has advanced from just a compliance requirement to a process instrument with a payback potential within days. What is it worth to the user to reduce power costs to an ESP by 1-2%? Only the plant itself can answer this question. However, if there are three ESPs with a total of 200KVA in power to each box, it is obvious that the savings are substantial.

If the usage of additives can be optimized (minimized), or the life of the equipment can be extended by 1-2 months due to better corrosion control, what is the value for these? These are questions that need to be answered by each individual plant.

However, what has been presented and made apparent is that these questions now have answers and the user can reduce operating costs with the use of a technology originally developed strictly for CAA compliance requirements.