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The What, Why and How of Opacity Measurement

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A power generation industry byproduct is the emission of smoke and dust from the stacks of combustion processes such as coal- and oil-fired generating units and industrial boilers. While it is true that the industry is moving away from burning coal to burning newly plentiful and cleaner natural gas in the U.S., coal use in the generation of power will likely stay in the 20% to 30% range.

These emissions potentially damage the environment and cause health challenges for those living close to power plants. In response, agencies such as the Environmental Protection Agency (EPA) in the U.S. and Environment Agency in the UK regulate the emissions by establishing an Emission Limit Value (ELV), the amount of smoke or dust emitted without incurring legal penalties. To ensure compliance, power-generation plant operators must measure either particulate matter (PM) emissions or opacity and monitor and report measurement results to demonstrate compliance with current regulations.

Particulate matter includes smoke, dust, ash, soot, aerosol and fumes. One of the most obvious signs of PM emissions is a visible plume of smoke leaving a power-generation stack. It is possible to measure the amount of light that passes through a gas containing PM, and light is lost through scattering, absorption or reflection by the particles. The loss depends on the number and the size of the particles and it is a measure of the PM concentration in the stack. A PM monitor measures optical characteristics of the stack gas, and uses the value to calculate the PM concentration in mg/m^3. The calculation uses a calibration factor, unique to that specific installation.

Opacity, in comparison, is a measure of light attenuation—the fraction of light lost in crossing the stack. An opacity monitor is also used to measure the optical characteristics of the stack gas. However, in this case, the light lost through absorption and scattering is converted into a useful number—the stack opacity—which is made available as an output percentage.

In general, opacity and PM measurements are only required on processes burning coal, oil and waste materials such as incinerators. Natural gas does not contain dust and ash, so gas-fired processes do not produce emissions of PM. But, as we'll see, many natural gas power generation facilities are still required to monitor and measure PM and opacity.

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Opacity and Emission Limit Value

The ASTM D6216 standard defines opacity as the degree to which particulate emissions reduce (due to absorption, reflection and scattering) the intensity of transmitted photopic light and obscure the view of an object through ambient air, an effluent gas stream or an optical medium, of a given path length.

These processes are illustrated in Figure 1, indicating light rays passing through a sample while others are scattered, absorbed or reflected.

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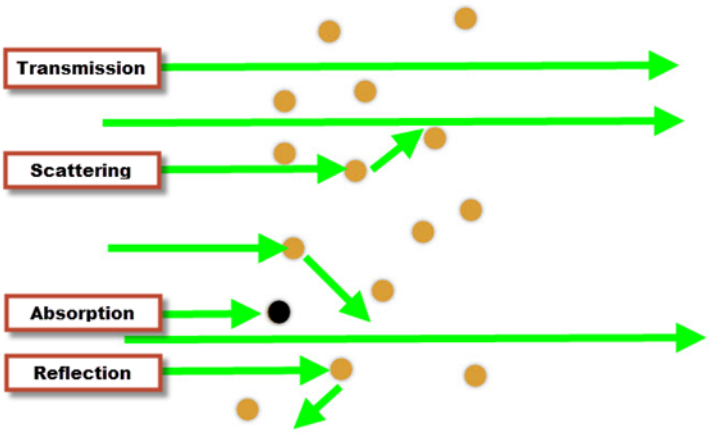

Figure 1. Dust particles scatter, reflect and absorb light.

Given the light intensity entering the sample is I_o and the intensity leaving the sample is I, opacity is mathematically expressed as:

$$\text{Opacity} = \left(1 - \frac{I}{I_o}\right) \times 100\%$$

Should the sample contain no particles, the intensities I and I_o will be the same, and opacity is 0%.

Figure 2. Sample with 0% opacity.

If the sample has particles that block all light, I = 0 and the opacity is 100%.

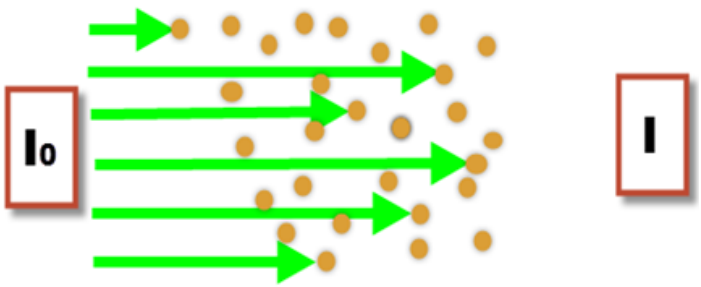

Figure 3. Sample indicating 100% opacity.

Some regulatory bodies set an emission limit value (ELV) in plume opacity at the stack exit. ELV can also refer to the mass concentration of PM emitted from the stack and be expressed as a mass concentration, as in 10 mg/m^3 or 50 mg/m^3. The EPA sets emission limits in % opacity, but recently is moving to the use of mass concentration units. European regulators have always set limits in mass concentration units. The choice depends on the compliance requirements of the local regulatory authorities.

Taking Measurements

Opacity monitors must operate reliably 24/7 and also be rugged. Often used in extreme conditions, they are mounted outdoors at an elevated position on a stack where they are exposed to temperature extremes. Given the size of stack structures, there is also minor movement and the monitor must accommodate this displacement.

ASTM D6216 is a consensus standard written by users and manufacturers, requiring that a monitor/analyzer must meet defined performance standards and earn a certificate of conformity.

Each opacity monitor must be configured and calibrated for the specific installation where it is used. Setting up requires that the following information be available and recorded:

- The distance between the outer faces of the flanges, which are permanently fixed to the stack, excluding adaptors or other accessories. This is used, along with a list of accessories, to calculate the installation path length.
- The installation path length dimension is the distance between the transceiver and retro mounting flanges and is always greater than a flange-to-flange path length.
- The U.S. EPA requires the measurement and exit path lengths.
- Measurement path lengths are the inside dimension of the stack or duct at the measuring point. Since standpipes are purged, the measurement path length is the distance the light beam travels through the dust-laden stack gases.

Exit path length is the inside dimension of the stack or duct at the point where gases are discharged to the atmosphere. The measurement and exit path lengths are used to calculate the path length correction factor (PLCF), which is then used to calculate the opacity at the stack exit, the location where regulations require it to be reported.

When there is a straight stack, for example, the PLCF equals 1.0. Tapered stacks have PLCF < 1.0 and installations where monitors are installed on a narrow duct leading to the stack, have a PLCF > 1.0. When the PLCF is greater than 1.0, any error effects are magnified.

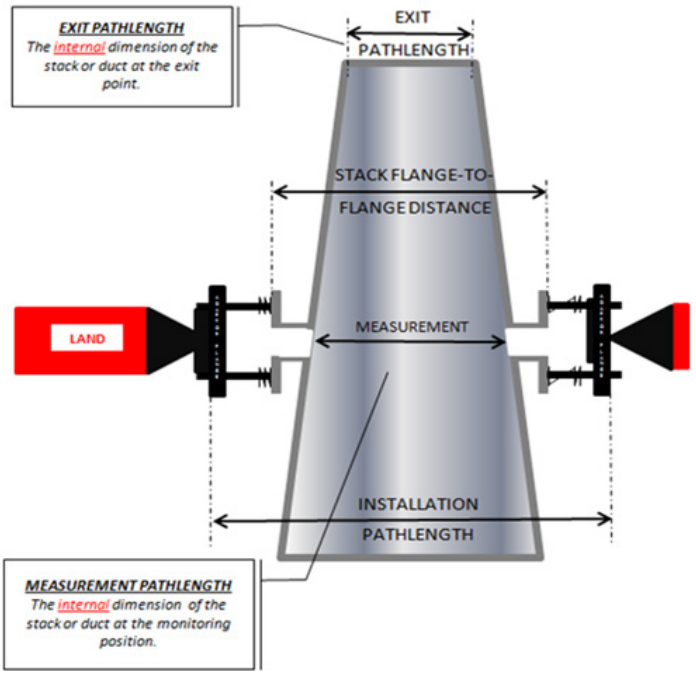

Figure 4. Path lengths required to configure an opacity monitor. Source: AMETEK Land.

Plant operators must not only meet the design requirements of ASTM D6216, they must also maintain a QA/QC written plan keeping records for the life of the monitor.

The AMETEK Land 4500 MkIII

The basic components of the AMETEK Land 4500 MkIII opacity monitoring system include:

- **Transceiver**—Contains the light source and detectors, user interface and main microprocessor.
- **Retroreflector**—Passive device which returns the light to the transceiver. Unlike a mirror, the light returns in the direction it came, regardless of the angle of incidence. It is much less sensitive to changes in alignment, which occurs as stack temperatures change.
- **Standpipes**—Mount the transceiver and retro to the stack, and enable adjustment of the instrument's optical alignment.
- **Purge Blower**—Use is mandatory to protect the instrument's delicate optical surfaces from the hot, corrosive stack gases.
- **Air Hose**—Connects the purge blower to the transceiver and retro.
- **Fail-safe Shutters**—Close automatically to protect optics if the purge fails temporarily. Protect the instrument and operator preventing stack gas escape when the instrument is removed from the stack for calibration and servicing.
- **AFU-APS-I/O**—The transceiver requires 24 V dc power and provides limited connectivity. The Auxiliary Function Unit, Auxiliary Power Supply and I/O module provide additional functions including two 4-20 mA signals, mains power input and convenient screw-terminal connections, which avoid the need for a customer-provided junction box.
- **External Zero Device**—Simulates a clear-path condition for servicing and for routing calibration checks, required for all applications subject to U.S. EPA regulations.

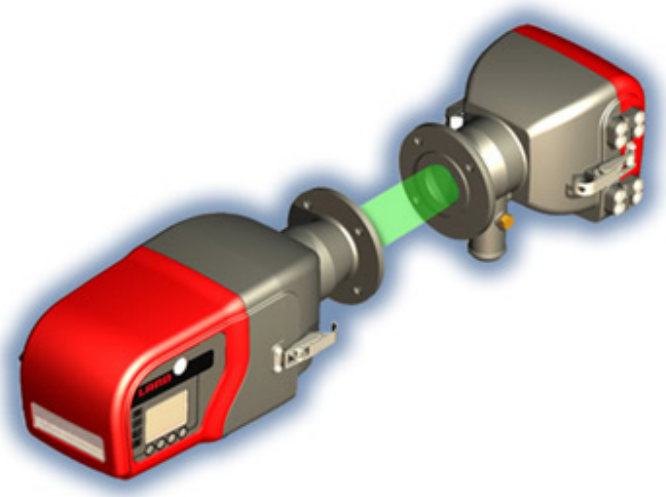

Figure 5. AMETEK Land 4500 MkIII Opacity Monitor. Source: AMETEK Land.

The AMETEK Land 4500 MkIII meets all U.S. and European regulations. It offers very high reliability, given that there are no continuously moving parts. Most modern opacity monitors, including the AMETEK Land Model 4500 MkIII, use a double-pass design, wherein a transceiver projects a beam of light across the stack to a reflector, which returns the light to a detector mounted in the transceiver. Advantages of the double pass design method include:

- Low-level sensitivity is increased since the light passes through the stack gases twice.
- No power is required at the reflector.
- A simulated zero condition is achieved by placing a reflector in the beam at the transceiver, short-circuiting the stack.

The solution also offers a standard wide temperature range to -40 °C (-40 °F), flexible configuration, easy maintenance and servicing and a lifetime warranty on the light source.

It is important to note that purge air must be used in opacity monitoring to protect sensitive instruments from hot, corrosive stack gases, by keeping the optics clean and preventing corrosion and contamination of mounting tubes (See Figure 6).

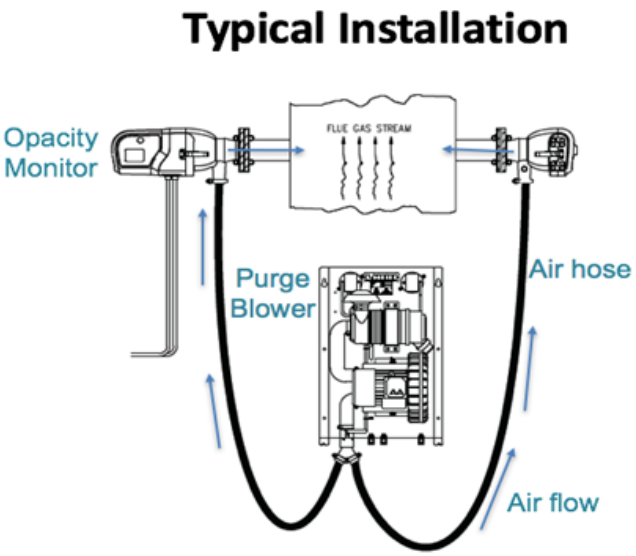

Figure 6. Laminar flow in purge air designs streamlines travel in the same direction so that stack gases are not drawn back into the purge nozzle. Source: AMETEK Land.

There are several options for air purging, including:

- Compressed air
- Air mover and blower

While there is a cost advantage to compressed air, a large volume of clean, dry air is required. It is usually impractical to deliver sufficient compressed air without putting stress on the on-site compressor. There would also be questionable air quality and unknown reliability in the use of compressed air. It is generally not recommended.

A side-channel blower delivers reliable filtered purge air. Based on the application, output from a single blower is split between both sides of the stack.

Basic weatherproofing is standard and a cover is required for exposed locations.

A pressure switch and pitot tube for sensing purge flow are recommended for all installations.

Why the AMETEK Land 4500 MkIII?

Opacity monitoring is not going away. The trend globally, in fact, is to push emission limits even lower. Even though the EPA is currently under political pressure, and there may be a slowing of regulations going forward, existing regulations are there to protect the environment and will be enforced. Globally, requirements are on the rise. The more sensitive the measurement, the more complex the monitor.

Even though natural gas is increasingly used for power generation, and unlike coal and oil, it does not require opacity measurements, producers may still need opacity monitors. Natural gas is not a storable fuel. Given the lack of storage, and the need to maintain a backup fuel many process operators maintain the ability to burn oil and so they are required to have an opacity monitor.

AMETEK Land can provide annual calibration of the device and is available to advise on complex underlying regulatory rules and how to stay in compliance with them. In a confusing and compliance-laden industry, the AMETEK Land Model 4500 MkIII coupled with the company's 70 years of experience and expertise, makes the purchase and use of an opacity monitor simple.

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ABOUT AMETEK LAND

AMETEK Land is a global supplier of non-contact temperature measurement instrumentation, process imaging solutions and combustion and environmental analyzers. Founded in 1947, LAND has been the premium supplier of temperature measurement solutions and combustion emissions monitoring.

AMETEK Land has facilities in the United Kingdom, China, France, Germany, India, Italy, Japan, Singapore, Spain and the United States.

The full range of non-contact temperature products includes high accuracy hand-held portables, fixed system spot temperature sensors, thermal line scanners, process thermal imagers and calibration sources. Many application specific systems solutions are available