Smoke Density Measurement in Municipal Incinerators

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Abstract

The opacity or optical density of smoke in the breeching or stack of a municipal incinerator is an index of combustion. The smoke meter is a useful operating guide, rapid in response.

The paper describes the theory and principles of the modern smoke meter and types of readout. It is a guide for the selection, specification and installation of smoke meters, smoke alarms, and recording smoke charts.

Introduction

Incinerator smoke originates in the furnace and is principally the visible cloud or plume of submicron particles of soot, dust, mist and fume from combustion. Gray or black smoke is caused by incomplete combustion of hydrocarbons. Refuse varies widely and often unpredictably in smoke-producing potential, yet smoke can be prevented by well-known combustion principles. It is important that smoke be prevented at all times for good public relations and to prevent nuisances and health hazards.

Smoke density is normally measured as degree of grayness or blackness by the Ringelmann chart [1]. The Ringelmann scale, 0 to 5, ranges from clear or white to jet black. As prescribed by the Bureau of Mines, the plume at the top of the stack is compared visually with the chart to obtain the smoke-shade number. As this is an inconvenient and impractical method of observation in daily plant operation, impossible at night, and is subject to human error of judgment, photo-electric meters have been developed and are in wide use.

Principles

The photoelectric smoke meter consists of a constant or compensated light source shining a beam of light across the flue gas in a breeching or stack, with a photo-electric cell receiving the unabsorbed light and indicating the degree of opacity on a meter.

The relation of the smoke density and the light is given by the Beers-Lambert equations:

\[ I = I_o e^{-knLD} \]

where: \( I \) is the intensity of the light transmitted through the smoke,
\( I_o \) is the original intensity of the light,
\( e \) is the base of natural logarithms, 2.71828,
\( k \) is a constant,
\( n \) is the concentration of smoke in particles per unit volume,
\( L \) is the length of the smoke column, and
\( D \) is the diameter of the smoke particle.

As \( L \) is constant and \( D \) is assumed constant, we can combine them in the constant \( K \), and by conversion to logarithms the expression is

\[ n = K \log \frac{I_o}{I} \]

Expressed simply, this means that if a certain amount of smoke cuts off 20 per cent of the light, twice the amount of smoke will not cut off 40 per cent but will cut off 20 per cent of the light remaining, that is, 20 per cent of 80. The total cutoff will, therefore, be 20 plus 16, or 36 per cent of the light.
The above equations contain simplified assumptions. Actually, the factor \( n \) will vary with the albedo (surface character) of the particles [2], [3]. It will also vary with the spectral characteristics of the light source and the spectral response of the receiver, either or both of which vary for differing equipment and installations. The diameters of the smoke particles are not uniform, nor will the mean size and shape always be the same. However, for our immediate purposes the equations are practical and useful.

Derivations from Eq. (1) will yield:

\[
\text{Per cent light transmission} = \frac{l}{I_o} \quad \text{and} \quad (3)
\]

\[
\text{Optical density} = \log \left( \frac{l}{\text{per cent trans.}} \right) = \log \left( \frac{I_o}{l} \right) \quad (4)
\]

It will be noted that neither \( n \) nor \( L \) appears in (3) or (4), which equations apply only when the distance is fixed and the spectral characteristic of light source and receiver are constant and the particle-size distribution, shape and albedo are uniform. Hence, they apply for an individual installation and effluent.

Note also that the indicator readings from photoelectric scanning for a given installation derive from transmission through the gases, while opacity equivalent to Ringelmann Number includes reflectance and is subject to variations in sky conditions.

The indicating meter is scaled 0 to 5, or 0 to 100 per cent, with zero equivalent to the Ringelmann zero, and 5 or 100 per cent equivalent to the Ringelmann No. 5. Between the limits the correlation with Ringelmann is subject to calibration tests on each installation. Such calibrations are rarely done because the findings are more academic than useful at the normal incinerator plant. Furthermore, the photoelectric meter gives accurate and reproducible results of most technical significance.

The smoke-meter readings are not a measure of dust loading and are not intended as such. This is obvious when one considers the wide ranges of particle sizes that dominate the weight of fly ash. For example, a spherical particle of fly ash 100 microns in diameter weighs 1 million times as much as a 1 micron particle, yet presents an area of only 10,000 times as much to obscure light.

Smoke meters are used on incinerators and boilers with and without dust collectors as their functions are independent.

### Selection and Specification

Many conventional smoke instruments are available for readout of the receiver output, such as indicating meters, recorders, alarms and overriding combustion controls. Careful selection of a complete system for an incinerator is imperative, as plants differ greatly in overdesign, operating methods, maintenance facilities and organization.

While the system may be by one manufacturer, it is often found advantageous to combine components of different makes. For instance, two or more ducts may be monitored, each by a scanner, indicator and alarm, all by one maker; and a multi-point recorder of another make may be added, connected to each indicator. Sometimes, where only one smoke record is required, one point or pen on a recorder for other variables may be used for smoke density. In either case, assurance of compatibility of scanning system and instruments is important in order that pointer deflections for given densities will be such as to provide a basis for readily establishing a correlation between pointer readings and observed density.

The system may be provided with red signal lights and an alarm. Alarm start should be adjustable at the instrument and preferably over the entire scale from "clear" to "dense", by means of a scaled index; there should be a negligible differential between signal start and stop. A "Duration of Excess" feature is sometimes advantageous on recorders. A pulsing signal with rate proportional to density of excess smoke is helpful to operators.

Stabilization for line voltage variations is important for incinerators where crane loads often cause wide fluctuation.

### The Scanning System

The scanning system is most important and deserves very careful study in selection and installation. Sturdiness of construction and mounting means provided by "heavy duty" types should be used on incinerators. If located outdoors or subject to damp conditions, weatherproof types of materials suited to the environment should be specified. The system must be capable of scanning at the distance required and producing suitable "pointer movements."

Self-aligning means are advantageous, providing design and installation are such that initial alignment is correct and will so remain. For other than self-aligned systems, the adjustment should be simple and so designed as to retain the original setting. Systems requiring accurate alignment of light source only are preferable to those which also require accurate alignment of receiver also.

A desirable feature, where available, is provision whereby the beam sensitivity versus density changes may be varied. Necessity for any adjustments at the scanning point, other than beam alignment, should be avoided. Such adjustment should be located where readout is visible, especially the "standardizing" adjustment for "clear flue" and for "dense," if this latter is not automatic.

The design should provide for easy cleaning, service, and lamp or other component replacement without disturbing alignment. Easily removable subassemblies with electrical connections by plug and receptacle facilitate service. The design should provide for ventilation and cooling as required, and be such that stray light will not reach the...
receiver to cause errors in readout. The fewer the electrical or electronic components in the scanning system the better. The effect of high ambient temperature should be determined and given due consideration.

**Scanning System Location**

So many factors must be considered that the "best location" is often a compromise. Only rarely will scanning of raw or unclean gases be desirable and discussion herein is limited to scanning for evaluation of final effluent as emitted to the atmosphere.

a. Scanning should be after the gas-cleaning facilities. As long as a representative sample is scanned, locations part way up the chimney or even through the stack pedestal are not necessary. Across a chimney flue just before the pedestal or across the intake duct to an I.D. fan discharging into a stack are good locations.

b. Horizontal beams, or nearly horizontal, are practically a "must". There must be a clear, unobstructed passage of sufficient diameter for the light beam from light source to receiver.

c. The location should provide accessibility for cleaning and service, and the ambient temperature must be suited to such service and the equipment.

d. Negative draft in the flue at the scanning point is highly preferable for ventilation and cooling. Air purging, required where draft is positive, is expensive and usually entails considerable extra maintenance.

**Scanning System Installation**

As with all instrumentation, it is especially important that specifications require strict adherence to the manufacturer's instructions for installation. Such instructions should be reviewed to determine if the location specified complies with them.

a. Flue or duct walls on which the light source and receiver are mounted must be stable and free from warping or buckling which would disturb beam and receiver alignment or cause distortion of the support tube or a self-aligning system. Independent support, other than on such walls, may be necessary.

b. Where sleeves are provided at each side, or where a full length sleeve is used, the installation must be such that differential expansion of inner and outer brick work, such as the outer column and liner in a chimney, will not cause misalignment or distortion of the sleeves with temperature changes.

c. Provide a peephole at light source end where required for checking beam alignment and flue conditions.

d. Substantial guards, to protect light source and receiver, should be provided if location is such that these might be subject to physical damage. If outdoors, a protective hinged hood, even for weatherproof equipment, is often desirable to prevent icing.

e. All mounting bolts or other threaded devices requiring future adjustment or removal should be liberally treated with high temperature and/or weatherproof grease.

**Electrical Installation**

a. Wires from a cabinet to a scanning system should be in separate conduits with no other wires except those for other scanning systems, where more than one system is installed. If required by the manufacturer, a separate conduit should be provided for the receiver and another for the light source. This provision for separation also applies to such wires not in conduit, as in cables within panel boards.

b. In general, wiring should comply with electrical specifications, particularly as regards insulation, moisture protection, and temperature conditions.

c. Watch manufacturer's instructions for possible limits on resistance or shielding requirements.

d. The use of separable connectors suited to the environment is advantageous at light source and receiver.

**Benefits of the Smoke Meter**

As applied to municipal incinerators, the photoelectric smoke meter has several uses and advantages;

1. It is not necessary to go outside to see whether the stack is smoking, nor to rely on mirrors. The meter reads smoke day or night with the same accuracy.

2. As an indicating meter it tells the operator promptly when combustion over the refuse bed is not up to standard.

3. The effectiveness of an adjustment to the air supply or stoker in reducing smoke is observed readily on the meter.

4. A smoke alarm notifies the operator when a change in refuse or other condition causes smoke unexpectedly.

5. A smoke meter in the superintendent's office tells him whether smoke is being produced while he is present.

6. A smoke recorder informs the superintendent whether smoke was produced on any shifts during the previous 24 hours, as well as the density and duration of the smoke.

**Conclusion**

A carefully selected, explicitly specified, properly installed and conscientiously maintained photoelectric smoke density system in a municipal incinerator can prove useful as an operating guide to firing, avoiding air pollution, and maintaining good public relations.

**References**


Bibliography


