EMISSION MEASUREMENT TECHNICAL INFORMATION CENTER
TECHNICAL INFORMATION DOCUMENT

Opacity of Combined Gas Streams

Introduction

Industrial processes often have two or more exhaust gas streams combined in a common stack. Often the individual exhaust gas streams are not alike, that is, they are significantly different either in opacity limitation, particulate concentration, flow rate, or in the physical configuration at the point of emission mixing. The use of continuous opacity monitor system(s) (COM) placed in the stack after the exhaust gas from multiple ducts are mixed or visible emission (VE) data taken from the same position in the single stack to assure either proper operation and maintenance or compliance with opacity limits is influenced by the prior combining of the gas streams. The results of combining gas streams should be understood when setting standards, evaluating and approving COMS locations, correcting COMS measurements to stack exit conditions, or certifying compliance. This monograph presents technical aspects of some compliance issues associated with combined gas streams.

The EPA new source performance standards (NSPS), 40 CFR Part 60, specifically §60.13(g) on the application of emission monitoring systems, addresses two distinct exhaust gas combining cases: (1) the combining of exhaust gas streams subject to the same emissions standard; and (2) the combining of emissions that have different opacity standards.

In the first case, §60.13(g) states "..that two or more affected facilities subject to the same emission standards are combined before being released to the atmosphere, the owner or operator may install applicable continuous emission monitoring systems on each effluent or on the combined effluent..," the wording of the regulation can incorrectly be inferred to allow "bubbling" of combined duct emissions, or that the monitoring of the combined stack exit emission is equivalent to monitoring the individual ducts. These are not acceptable conclusions and any single monitor proposals should be closely reviewed by the approving agency prior to acceptance. "Bubbling" as used in this document means that after combining the stack (duct) emissions into one common stack, only one emission limit would apply to the combined stack emission.

The second case in which gas streams subject to different opacity limits are combined, §60.13(g) specifies that "When the affected facilities are not subject to the same emission standards, separate continuous monitoring systems shall be installed on each effluent..." Monitoring of the individual gas stream opacities is judged to be the only way to ensure compliance and the emissions are not allowed to be "bubbled."

The NSPS does not address the application of Method 9, VE, evaluations under these above cases. This is an important concern because the impact of combined exhaust gas streams affect these readings as well, and not all sources with opacity limitations are required to install, operate, and maintain COMS.

Opacity of Individual Gas Streams

Whenever a flue gas stream contains particulate matter, the transmission of light through the gas stream will be reduced. The reduction is due to a combination of particulate absorption and scattering of light. The percentage of transmitted light attenuated by scattering and absorption is referred to as the "opacity" of the gas stream. Percent opacity (Op) and percent transmittance (Tr) are related by the expression:

$$Op = 100 - Tr \qquad \text{Eq. 1}$$

Another expression used to characterize the exhaust gas stream opacity is the "optical density" (D) of the stream. Optical density is related to the gas stream opacity in that as D increases, the Op increases. Mathematically, this is represented as follows:

$$D = -\log\left(\frac{Tr}{100}\right) = -\log\left(1 - \frac{Op}{100}\right) \qquad \text{Eq. 2}$$

The opacity and optical density of a gas stream depend upon the optical pathlength (depth of effluent) and volumetric flow rate of the gas stream.

Figure 1 shows a particulate-laden gas stream of optical density D_1 and opacity Op_1 flowing in a duct having an inside diameter of d_1, exiting a stack with an exit diameter of d_x. The opacity and optical density at the stack exit are designated Op_x and D_x.

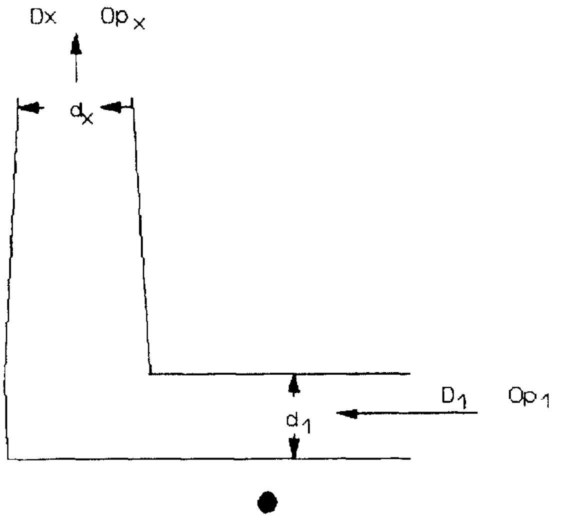

Figure 1.

The duct Op_1 and the stack exit Op_x are related mathematically to D_1 and D_x, as follows:

$$Op_1 = 1 - 10^{-D_1} \qquad \text{Eq. 3}$$

$$Op_x = 1 - 10^{-D_x} \qquad \text{Eq. 4}$$

Opacities Op_1 and Op_x will be equal when the optical densities, D_1 and D_x are equal. The duct and stack optical densities are related as follows:

$$D_x = D_1 \left(\frac{d_x}{d_1} \right) \qquad \text{Eq. 5}$$

Equation 5 shows that D_x and D_1 (and consequently Op_x and Op_1) will be equal only when the exit inside diameter and the duct measurement depth, d_1, are the same. Very often, Op_1 and Op_x will be different prior to correlation for the depth of the monitored gas stream.

Equation 5 assumes that the particulate concentrations are the same in the duct and at the stack exit. If a particulate control device is located between the duct and stack exit locations, the mathematical relationship of Equation 5 is no longer valid due to the change in the concentration and aerodynamic size distribution of the particulate.

Opacity of Combined Gas Streams

The opacity and optical density of combined gas streams at the stack exit are influenced by the individual gas stream volumetric flow rates, as well as the optical pathlengths of the individual ducts. Consider the following emission point configuration of Figure 2:

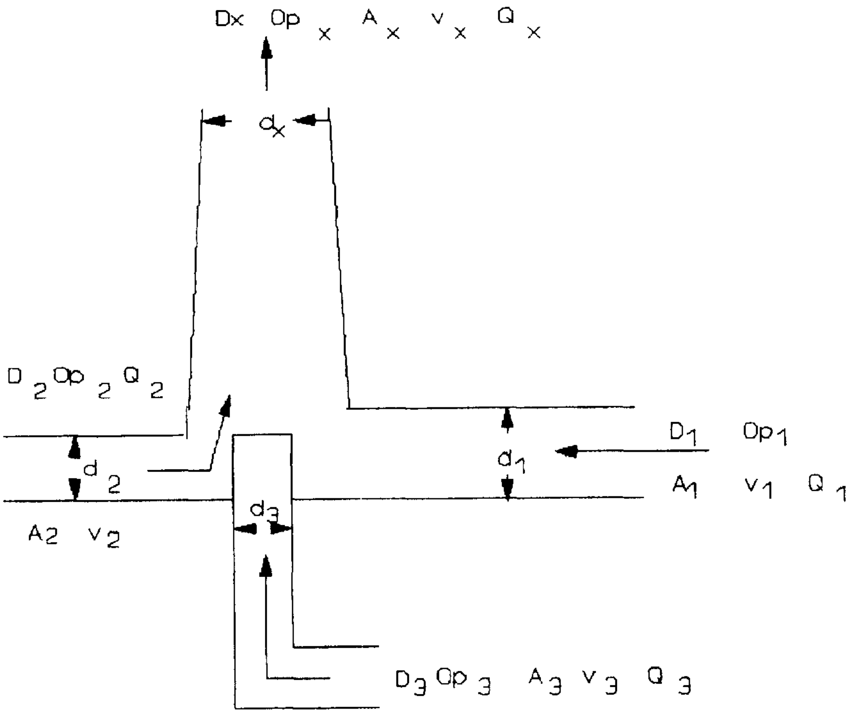

Figure 2.

In Figure 2:

D_i = Optical density of individual gas streams in the ducts, (i=1,2, or 3).

D_x = Optical density of combined streams at the stack exit.

d_i = Individual duct diameters, (i=1,2,or 3).

d_x = Stack exit diameter.

A_i = Individual duct cross-sectional areas, (i=1,2, or 3).

A_x = Stack exit cross-sectional area.

v_i = Individual velocities of gas streams in ducts, (i=1,2, or 3).

v_x = Stack exit gas stream velocity.

Q_i = Individual volumetric flow rates in the ducts, (i=1,2, or 3).

Q_x = Flow rate at stack exit (total combined flow).

Op_i = Opacities of the individual gas streams in the ducts, (i=1,2, or 3).

Op_x = Opacity of the combined streams at the stack exit.

The optical density of the combined gas streams at the stack exit is calculated by means of the following equation:

$$D_x = \frac{\sum_{i=1}^{n}\left[(D_i \times Q_i) \times \left(\frac{d_x}{d_i}\right)\right]}{\sum_{i=1}^{n} Q_i} \qquad \text{Eq. 6}$$

where

n = number of combined gas streams.

Equation 6 is referred to as the "combiner equation."

Dilution Effects

When two or more gas streams of different opacity (optical density) combine, "dilution" of the higher opacity gas stream by the lower opacity (cleaner) gas stream must occur. At least one of the two or more combined gas streams could be out of compliance prior to being combined. Dilution effects by the clean exhaust gas stream(s) can "mask" the noncomplying condition to the extent that the diluted opacity at the stack exit appears to comply with the standard. This would be true regardless of the opacity standard that applies to each individual gas stream.

Dilution effects can be represented mathematically, using a reduced version of Equation 6. The individual flow rates, Q_i, can be expressed as decimal fractions of the total flow rate at the stack exit, Q_x. In our example above, $Q_1 = aQ_x$, where "a" is the ratio of the flow in Duct 1 to the total flow at the stack exit. Equation 6 can, therefore, be written as follows:

$$D_x = \sum_{i=1}^{n}\left(\frac{Q_i}{Q_x} D_{xui}\right) \qquad \text{Eq. 7}$$

where: D_{xui} = Optical densities of the uncombined (unmixed) exhaust gas streams at the stack exit assuming no contribution from other exhaust streams.

For the Figure 2 configuration, Equation 7 becomes:

$$D_{xm} = \frac{Q_1}{Q_{xm}} \times D_{xu1} + \frac{Q_2}{Q_{xm}} \times D_{xu2} + \frac{Q_3}{Q_{xm}} \times D_{xu3} \qquad \text{Eq. 8}$$

The stack exit optical densities obtained can be converted to opacity using Equation 4.

For Figure 2, dilution effects will be maximum when two gas streams, combining with the third, have optical densities (opacities) of zero. Referring to Figure 2, consider the case of maximum dilution of stream No. 1. Substituting a "zero" optical density for gas streams 2 and 3 in Equation 8, we identify a dilution impact Equation as follows:

$$D_x = \frac{Q_1}{Q_x} \times D_{xu1} \qquad \text{Eq. 9}$$

The D_x is the actual observed optical density at the stack exit after exhaust Duct 1 has been combined with the two clean streams. Hence, D_{xm}, is a decimal fraction of D_{xui}, the optical density that would have been observed if no dilution had taken place. As the ratio of the individual flow of optical density not equal to zero to the total flow increases, the undiluted and diluted optical densities (and opacities) will become nearly the same; therefore, the possibility of masking non-complying opacity will be small. Conversely, as the ratio of Q_1 to Q_x decreases, the likelihood of masking a high opacity increases.

Compliance Considerations

1. When exhaust gas streams combine prior to discharge to the atmosphere, the opacity of the combined gas stream can be significantly higher than the lower opacity streams or significantly lower than the higher opacity streams.

2. When gas streams combine, it is possible for noncomplying component stream opacities to be concealed by dilution effects.

3. The potential for dilution effects to mask a non-compliant gas stream increases as the opacities of the lower opacity diluent streams approach zero percent or the volume percentage of the lower opacity diluent gases in the combined exhaust gas approach 100 percent.

4. If the relative volume percentages of the component streams are known, it is possible to determine a suitable stack exit opacity limit that would prevent "masking." This concept may be useful in "steady-state" processes in which the component gas stream flow rates remain in relatively constant proportion by volume, independent of the process load.

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