Comparison of Continuous Opacity Monitor and Method 9 Observations to Triboelectric Broken Bag Detector Signals on an EAF Baghouse

A 45-day test program comparing output of a triboelectric broken bag detection system to a continuous opacity monitor was conducted on an EAF/LMF baghouse at Ipsco Steel Inc., Montpelier Works, from Oct. 12 through Nov. 25, 2000. During the test, elevated opacity was artificially created to better identify the comparison at opacities higher than 5%. U.S. EPA Method 9 visible emission observations were made concurrently during the surrogate particulate introduction periods.

Ipsco Steel Inc., Montpelier Works, was interested in replacing the continuous opacity monitor (COM) installed on its EAF/LMF baghouse stack due to New Source Performance Standard (NSPS) requirements. The COM had been a high maintenance device due to high vibrations on the negative pressure baghouse stack. Further, the COM had a documented problem measuring the 3% opacity standard applied to the EAF emissions. Bag penetration by sparks in the negative pressure, pulse jet baghouse had been a continuing maintenance problem, and the COM had shown itself to be ineffective as a tool for identifying failed bag compartment locations. When opacity was identified in the stack, the COM provided the operator with no useful information as to emission source. When more than one compartment was involved, successive isolation of individual compartments provided no compartment identification information when using the COM as the emission indicator.

To provide operators with a more proactive and useful tool, Ipsco investigated the feasibility of using a broken bag detection system. After a review of broken bag detection system technologies, a triboelectric base system was selected.

Due to the lower levels of particulate change detected by the triboelectric technology and the problems associated with using a COM in this application, Ipsco applied to the U.S. EPA to use alternative monitoring technology on the EAF/LMF baghouse. The use of a triboelectric broken bag detection system was proposed for replacement of the COM originally installed on the stack. The proposed technology change was conditionally approved by the U.S. EPA, provided that Ipsco run a 45-day comparison test to establish the relative relationship of the triboelectric signals to opacity as measured by the COM. As compliance with the NSPS 3% opacity standard for the EAF baghouse was established by visible emission observations using U.S. EPA Method 9, such observations were also included in the comparison by Ipsco.

Instrument Measurement Mechanisms

Fundamental compliance with the particulate standard for EAF emissions is based on particulate mass emissions from the baghouse. With continuous monitoring of mass emissions remaining a practical impossibility for fume control systems, the use of surrogate measurements has been adopted to characterize baghouse particulate emissions. The surrogate measurement adopted by the U.S.

Authors

Joseph C. Wesselman, Corporate Director—Environmental Affairs, Ipsco Enterprises Inc., Lisle, Ill., and **Charles W. Askins**, President, AG Environmental Services, Inc., Victor, N.Y. (jwesselm@ipsco.com)

EPA in the NSPS for the EAF baghouse was relative opacity. Opacity is the measurement of the amount of light lost when passing through an emission plume, and is characterized by percent loss of light. The opacity measurement range is 0 to 100%, with zero being no loss and 100% being a complete loss of light (fully opaque).

U.S. EPA established a standard method of visual evaluation for particulate emissions that uses a trained human observer to establish opacity of exhaust plumes. This procedure is found in 40 CFR 60 as Reference Method 9 (U.S. EPA Method 9). The requirement for visual opacity measurements using U.S. EPA Method 9 was established in the Ipsco EAF NSPS to allow operators and regulators to monitor EAF baghouse compliance with the particulate mass emission standard.

The measurement of opacity (by either Method 9 or a COM) and the measurement of triboelectric change are all surrogate measurements for the mass emissions from the baghouse, and measure the amount of particulate present in an exhaust gas stream. None of these systems measure true particulate mass emissions.

COM System

Opacity can be measured using an instrument such as a COM. The COM uses the same basic principle as Method 9 observations, measuring the loss of light associated with passage of a light though an exhaust plume. In the case of a COM, the source of light is a beam that is directed across a duct or stack striking a mirror on the opposite side of the duct. The mirror is aligned to reflect the light back to the light source. The instrument measures the reduction in light intensity after this double path length, and calculates the loss as relative opacity.

COM opacity measurement is based on the principle that particles present in the gas stream affect the amount of light returning, as particles have inherent and variable characteristics of light absorbency, refraction or reflection. These characteristics are associated with the size, shape and structure of the respective particle, and quantity of particles present in the gas stream, but are not associated with the respective particle density or mass. COM presumes that all light lost is due to particles in the gas stream.

As there is neither a correlation to the gas flow volume nor the concentration of particulate present, mass emission associated with a gas flow cannot be measured by COM.

Opacity, whether measured by Method 9 or COM, is a qualitative surrogate for the quantity of particulate matter being emitted. The NSPS for opacity from the EAF/LMF baghouse is <3% opacity averaged over six minutes of continuous readings. The human eye can distinguish opacity to the level of 5% increments, and the minimum detectable change recorded by the human eye is 5%. Therefore, the EAF NSPS of <3% opacity is not a visible emission standard. COM is able to measure opacity in fractions of a percent, however it has been identified by ASTM D6216-98 to be accurate only to the level of 10% opacity.[1]

Triboelectric Broken Bag Detector System

The measurement principle of a triboelectric broken bag detection system is based on measuring small changes in the electrical charge of an energized probe placed in the exhaust gas stream. The probe is a stainless steel or other metallic material rod that is energized with a DC electrical voltage. Particulates present in the gas stream strike the probe and change its electric field, similar to the release of static electricity. The small changes in the electric field associated with the particle impacts are measured in picoamps and are readily quantifiable. The triboelectric signal is an analog output displayed as a percent of scale. The impact of no particles is measured as 0%, with the relative increase of particle strikes measured up to 100% of the scale.

Similar to COM, particle characteristics of size, shape and structure, as well as the quantity of particles present in the gas stream affect the relative change in triboelectric signal. However, these factors are not related to density or mass of the respective particle.

Equipment Specifications and Descriptions

System specifications for instruments used in the comparison are described here.

COM System — The COM system installed by Ipsco for use on the EAF/LMF baghouse was manufactured by Sick, Inc. Measurements are displayed on a monitor as instantaneous opacity and most recent six-minute average opacity. The COM instrument is installed on the baghouse stack at the sample testing port level on the stack, approximately 75 feet above grade. The total stack height is 150 feet above grade. The monitor is located at grade in the baghouse control building immediately east of the baghouse structure.

The signal from the COM reads out as a digital display on the console face of the controller. For the purpose of tracking COM data during this comparison, the COM 4-20 mA signals (instantaneous and six-minute average opacities) were connected to an

Table 1

COM Specifications

Manufacturer	**Sick, Inc.**
Model	OMD 41
Number of locations	1
Material of construction	Carbon Steel
Ambient temperature range	-4 to 131°F
Relative moisture	95%
Signal output	4-20 mA
Operating system	Dedicated COM software

Auburn computer. A real-time readout was available on the PC monitor, and a record of these signals was tracked and stored on the PC hard drive. COM system specifications are presented in Table 1.

Broken Bag Detector System — The broken bag detection system installed by Ipsco for use on the EAF/LMF baghouse was manufactured by Auburn Systems, Inc., and uses the triboelectric principle of particle detection. Triboelectric system specifications are presented in Table 2.

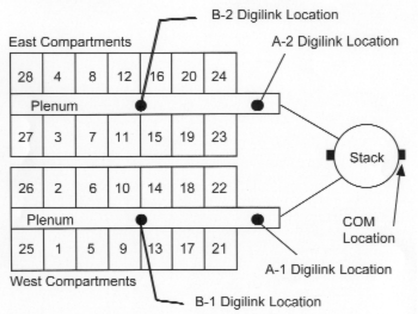
Table 2

Triboelectric System Specifications

Manufacturer	**Auburn Systems, LLC**
Model	Tribolink™
Number of probe locations	4
Number of sensors/location	2
Detector material of construction	316 Stainless Steel
Probe temperature range	-40 to 450°F
I/O interface	PC
Operating system platform	Windows 98

Tribolink detectors are located in four locations in the exhaust plenum of the baghouse. Two Tribolink detectors (A-2, B-2) are located in the east compartment group plenum, and two detectors (A-1, B-1) are located in the west compartment group plenum. Each detector group includes two probes. The detector configuration design places the probes such that there are eight compartments upstream of the B group probes, and 14 compartments upstream of the A group of probes. Figure 1 illustrates the general orientation of the baghouse compartments and the respective locations of the Tribolink detectors and the COM.

Figure 1



EAF baghouse compartment configuration and broken bag detector locations.

EAF/LMF Baghouse

The EAF/LMF baghouse is a negative pressure, pulse jet cleaning design that was installed for fume control of an EAF and LMF meltshop subject to the NSPS for EAFs. The negative pressure baghouse has a stack exhaust, and thus, must install and operate a COM on the exhaust stack.

The EAF is a twin shell DC single electrode design, initially created to produce at the rate of 164 tons per hour. At this base design rating, the EAF baghouse was sized and permitted to operate using 24 compartments, with one compartment off-line for service and/or cleaning during operations. The baghouse (under a phased PSD permit) was permitted and built to allow for the EAF to operate at a production rate of 200 tons per hour. At the 200 tons per hour rate, the baghouse system was designed to operate with 28 compartments, with one compartment off-line for service and/or cleaning during operations.

During the surrogate particulate introduction tests and the 45 day comparison period, the EAF was operating within the 164 tons per hour permitted production range.

Equipment QA Prior to Comparison Testing

Prior to beginning the comparison, a manufacturer's calibration was conducted on the respective instrument and monitoring system. A manufacturer's calibration conducted by Sick during the period of Sept. 25-28, 2000, insured that the COM conformed to the manufacturer's specifications. On Sept. 26, 2000, the output signal from the COM was connected to the Tribolink PC and verified as to its equivalence with the COM console display. The signal interface to the computer continued to operate without problems throughout the comparison period. Each of the Method 9 observers used during the comparison possessed current certifications.

Problems with COM Performance

As noted previously, the COM was initially calibrated by the manufacturer prior to beginning the U.S. EPA requested comparison on Oct. 12, 2000. The manufacturer's technician was on site for two days during the pretest calibration period. However, the COM continued to perform erratically throughout the test period, and was recalibrated a total of three times before and during the comparison. Manufacturer's calibrations were conducted on the following dates:

- Sept. 25-28, 2000
- Oct. 18, 2000
- Nov. 6, 2000

Ipsco was concerned that the COM should operate as closely as possible to the manufacturer's performance specification and the U.S. EPA Performance Specification 1, Appendix B of 40 CFR 60 (PS-1). Therefore, the company elected to have all of the calibration work done by the manufacturer's trained technicians, presuming that a superior level of calibration would be obtained. After the completion of the comparison study, the COM was evaluated by a qualified engineer for conformance with PS-1. This conformance certification was requested by the U.S. EPA, and the instrument was certified as conforming to PS-1.

The circumstances associated with the repeated calibrations during the comparison study by event date are discussed below.

Sept. 25-28, 2000 — As previously noted, this calibration was performed with the intent that the COM would be at its best operating performance before beginning the comparison. When the calibration was complete, the COM appeared to operate in accordance with the Method 9 observations made on the stack exhaust plume.

Oct. 12, 2000 — Prior to beginning the surrogate particulate comparison program on Oct. 12, 2000, it was observed that the COM was reading an average opacity of 4.9%, despite the fact that the meltshop was not operating, and there were no emissions. The weather was clear—the temperature was 65°F with prevailing winds at 5 to 10 mph from the southeast. Surrogate particulate (iron oxide) was introduced into the baghouse exhaust plenum to verify the relative performance of the COM. The COM did respond to increased levels of exhaust opacity. However, the unit never returned to 0% following dust introduction when visible emission observations using Method 9 showed an opacity of 0%.

Given the poor performance of the COM at low level opacities, a second calibration of the instrument was requested. Routine daily and additional Method 9 observations were made during the time period of Oct. 12-18, when the COM was recalibrated to confirm 0% opacity in the exhaust plume, although the COM indicated opacities ranging from 3 to 10% during this time period.

Oct. 18, 2000 — The COM was inspected on Oct. 18, 2000 by a technician from Spectrum Systems, the manufacturer's representative, and some reprogramming was done. The complete instrument package was recalibrated. When the technician left the site the COM was reading 0% opacity—the same opacity level recorded by stack exhaust plume Method 9 observations.

Nov. 1, 2000 — Surrogate particulate (iron oxide) comparison was scheduled for Nov. 1, 2000, and the COM was observed at 0% opacity prior to beginning the introduction of particulate. The weather was clear; the temperature was 70°F with prevailing winds at 10 to 15 mph from the southeast. The COM registered no change in relative opacity when the surrogate particulate was introduced into the exhaust plenum of the baghouse. Yet, Method 9 observations indicated opacities ranging from 5 to 25%. It appeared that the COM was in a flat-line signal mode, even though no adjustments had been made to the unit since the technician calibrated the unit on Oct. 18, 2000. The COM continued to read 0% opacity or nearly 0%, despite introduction of surrogate particulate.

A third COM recalibration was requested from the manufacturer, with the requirement that Sick provide the best technician available to correct the problems experienced to-date with the COM unit. The opacity indicated by the COM remained at 0% until Nov. 6, 2000.

Nov. 6, 2000 — The COM was again inspected on this date by a Sick technician from its German home office. The technician made programming changes to correct the flat-line signal induced by portions of the programming done by the Spectrum Systems technician. The complete instrument package was again recalibrated. After recalibration by the Sick technician, the COM erroneously read false-positive opacities between 5.0 and 6.0% when there were no meltshop operations. The Sick technician instructed Ipsco engineering personnel on the procedure to zero the COM during non-operating periods, and this procedure was performed. After the zero procedure was performed, the COM read 0% opacity during nonoperating periods, as well as during operating periods as verified by Method 9 observations. It became evident after a few days that the COM read a true 0% opacity only on dry days (low relative humidity). When relative humidity was high, the COM read a baseline of 3.0 to 4.0% opacity, even during nonoperating periods. This elevated, false-positive baseline opacity reading was evident during the two days of surrogate particulate comparison done on Nov. 15-16, 2000.

Broken Bag Detector System

Presently, there are no triboelectric-based system performance specifications published in 40 CFR 60, Appendix B. However, the U.S. EPA published a guidance document for such systems.[2] A broken bag detector system certified calibration was completed by Auburn on the broken bag detector system during the period of Sept. 20-21, 2000. During this calibration, all of the detector probes were removed, inspected and cleaned. The system operated throughout the comparison period without hardware or software problems.

General Objectives of the Instrument Comparison

The U.S. EPA did not establish any specific objectives for the comparison beyond that it must be conducted for a period of 45 days. To better qualify expectations for the comparison, several objectives were identified by Ipsco for the 45-day comparison. The following objectives were accepted by the U.S. EPA prior to beginning the comparison:

- Identification of a baseline normal range for triboelectric signals from each of the four detector locations.
- Comparison of the relative detection ranges for the COM and triboelectric system.
- Comparison of the real-time reliability between the COM and the triboelectric system.
- Introduction of iron oxide into each of the two clean-side plenums upstream of both detector groups in the respective plenum to compare system performance at opacities above 5%.
- Establishment of the relative relationship between the COM and triboelectric systems.
- Establishment of the relative relationship between the triboelectric system and Method 9 observations.

Comparison Study Discussion

As previously noted, the comparison study program began on Oct. 12, 2000. Findings from the 45-day comparison and a specific review of the two surrogate particulate introduction tests performed to evaluate tracking of higher opacity levels in the exhaust plume are discussed.

Comparison Test Program — Ipsco generally divided the comparison test program into two programs: comparisons during surrogate particulate introduction and comparisons during scheduled operations.

As it was anticipated that opacity levels above 5% would not occur during normal baghouse operation, Ipsco determined that a program to artificially generate elevated opacity levels would be required during the comparison program. The test program for surrogate particulate introduction was initiated late in the comparison period because of the difficulties encountered with the COM. The surrogate particulate introduction was done Nov. 15-16, 2000. The meltshop did not operate on Nov. 15, but did operate on Nov. 16, providing a particulate base load associated with fume collection for the comparison study.

During the surrogate particulate tests, Ipsco established the following objectives:

- Identification of a baseline normal range for triboelectric signals for each of the four detector locations.
- Introduction of iron oxide into each of the two clean-side plenums upstream of both detector groups in the respective plenum.
- Introduction of the iron oxide for a sufficient time period to allow for at least two successive six-minute observations by a certified Method 9 observer.
- Conducting a total of two tests in each of the plenums.
- Achievement of at least a 3% opacity for the tests, as identified by the COM and the Method 9 observer.
- Generation, if possible, of opacities of at least 20% during the comparison.

Particulate Introduction Method — Creation of opacity through bag penetrations to allow for EAF dust leakage was considered. However, this method of opacity creation was not used for several reasons:

- Bag penetration destroyed good equipment.
- The amount of dust could not be regulated.
- It was not possible to generate data for a single probe group. Once the bags were penetrated, they would continue to leak particulate until replaced.
- Use of penetrated bags does not produce a range of data for opacities.

Table 3

Particle Size Distribution Summary

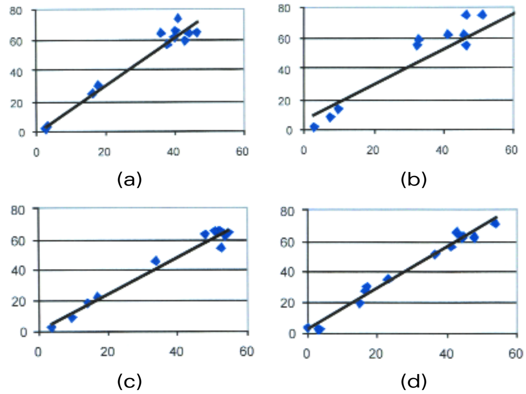
	10%	25%	50%	75%	90%
EAF dust (µm)	<1.235	<1.581	<1.874	<2.107	<2.276
Fe_2O_3 (µm)	<1.022	<1.328	<1.780	<2.346	<2.819

Table 4

VE to Triboelectric Signal Regression and Correlation Data

Location	Regression	Correlation (R^2)
Test No. 1, Probe A-1	y = 1.5634 x – 0.1031	0.9646
Test No. 2, Probe A-1	y = 1.155 x + 7.0787	0.8210
Test No. 3, Probe A-2	y = 1.1969 x + 0.4331	0.9734
Test No. 4, Probe A-2	y = 1.358 x + 2.2674	0.9791

Figure 2



Linear regressions of Method 9 observations to triboelectric signals on Nov. 16: (a) A-1 probe, Test No. 1; (b) A-1 probe, Test No. 2; (c) A-2 probe, Test No. 3; and (d) A-2 probe, Test No. 4.

Instead, surrogate particulate was introduced using a compressor, sandblasting pot and a single introduction point in the respective exhaust plenum. The dust introduction point was located up stream of the "B" probe locations in the respective plenum as shown in Figure 1.

Compressed air for conveying particulate was supplied from a compressed air line located at the penthouse level of the baghouse. The sandblasting pot and hoses were moved from the introduction location in the east compartment line to the west compartment line for the successive comparison runs. The introduction points were under negative pressure, and dispersion of the dust within the plenum was accomplished by the natural draft and turbulence in the respective plenum.

Particulate Size Distribution — A commercial grade of iron oxide (Fe_2O_3) was purchased for use as the surrogate particulate, and samples of the Fe_2O_3 and EAF dust collected by the baghouse were submitted for particle size analysis at an independent laboratory. The Fe_2O_3 mean particle size was 1.857 µm, while the EAF dust mean particle size was 1.818 µm. The iron oxide used as a surrogate particulate had particle size distributions similar to EAF dust (Table 3).

Comparison of Method 9 Opacity Observations and Triboelectric Signals during Particulate Introduction — A comparison was made between the Method 9 opacity observations and triboelectric signal output during the Nov. 16 surrogate particulate introduction. Method 9 observation data correlated very well for the four particulate introduction periods on Nov. 16. Figure 2 illustrates the linear regression curves of the Method 9 opacities to the triboelectric signals for the four introduction periods.

The Method 9 opacity points are for one-minute averages of 15-second readings according to U.S. EPA Method 9. Triboelectric signals are also based on one-minute average signal measurements for the corresponding period. Linear regression of Method 9 opacity to the triboelectric signals produced the equations, with associated R^2 values, presented in Table 4. Regression analyses of the B-1 and B-2 probes with the Method 9 opacity observations showed similar correlations.

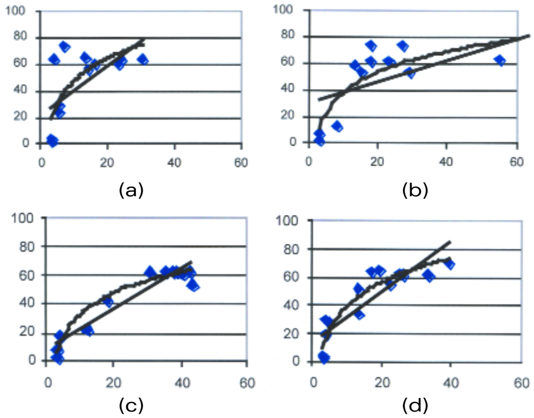
During the surrogate particulate comparison conducted on Nov. 16, the weather changed. The sky became overcast; the temperature was 38°F at the start of the comparison, and snow flurries began by the end of the fourth test.

Comparison of COM and Triboelectric Signals during Particulate Introduction — Throughout the test period, the COM indicated a base level opacity at 3 to 4% while according to simultaneous Method 9 readings there was no observable opacity in the exhaust plume. The false-positive baseline opacity was reported by the COM the entire day.

For comparison purposes, the same triboelectric signal data was plotted against the COM data. The COM opacity to the triboelectric signals (A-1, A-2 probes) for the four tests on Nov. 16 were plotted as logarithmic and linear regression curves (Figure 3). The COM data points are one-minute averages of COM continuous opacity output signal, and the triboelectric data points are one-minute averages from that system's signal output.

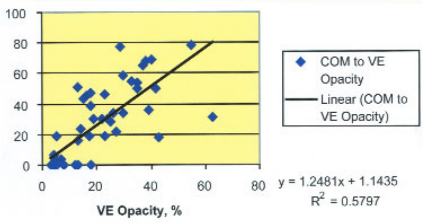
The respective regression curve formulae for the triboelectric to COM signal comparison, with the associated R^2 values, are presented in Tables 5 and 6.

Figure 3



Logarithmic and linear regressions of COM measurements to triboelectric signals on Nov. 16: (a) Test No. 1, A-1 probe; (b) Test No. 2, A-1 probe; (c) Test No. 3, A-2 probe; and (d) Test No. 4, A-2 probe.

Figure 4



Comparison of COM to Method 9 opacity during surrogate particulate introduction on Nov. 16.

The data plots for the comparison of these signals do not appear as linear as the Method 9 opacity comparison (Figure 3). Generally, the R^2 values for the regressions are much higher for the logarithmic regressions than for the linear regressions. The variation of the comparisons is somewhat related to the variability of the COM data as compared with Method 9 observations taken on a real-time basis.

Figure 4 shows a comparison of COM and Method 9 data taken on Nov. 16 during the surrogate particulate introduction periods. Regression analysis of the data collected on Nov. 15 during the set-up work indicated the same type of relationship. The correlation shows that the COM readings are generally higher than the Method 9 observations.

Evaluation of the Regulatory Relationship of COM and Method 9 Opacity to the Triboelectric Signals — Compliance with the 3% opacity standard is based on an average of opacities measured or observed during a six-minute interval. Comparison of COM and Method 9 data to the triboelectric signals using a six-minute average provides a different statistical population of points for comparison. The data averaged over six minutes for the respective instrument or method diminishes some of the swings measured on an instantaneous basis. The COM and triboelectric instruments take measurements on a frequency of two times per second, and Method 9 measurements are made every 15 seconds. Using measurements for all of the probe groups, averaged over six minutes, logarithmic regression analysis of triboelectric to COM signals produced the curve and formula presented in Figure 5, with an R^2 value exceeding 84%. All data points are based on real-time measurements.

Analysis of Method 9 opacity to triboelectric signals produced a linear regression (Figure 6) similar to analyses of individual probe groups compared to their respective Method 9 observations. The distribution of the data does not provide a basis for logarithmic regression, and the resulting linear regression function has an R^2 value of 63%.

Table 5

COM to Triboelectric Signal Linear Regression and Correlation Data

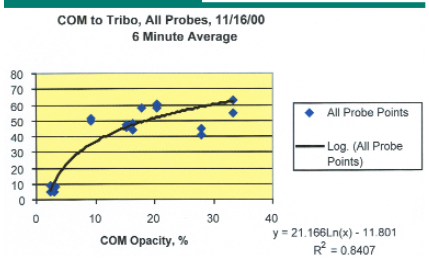
Location	Linear regression	Correlation (R^2)
Test No. 1, Probe A-1	y = 1.878 x + 22.485	0.4054
Test No. 2, Probe A-1	y = 0.7932 x + 31.156	0.3311
Test No. 3, Probe A-2	y = 1.4231 x + 8.8582	0.8854
Test No. 4, Probe A-2	y = 1.8411 x + 13.226	0.7561

Table 6

COM to Triboelectric Signal Logarithmic Regression and Correlation Data

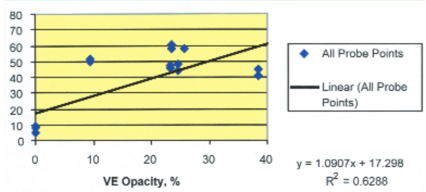
Location	Logarithmic regression	Correlation (R^2)
Test No. 1, Probe A-1	y = 24.205 Ln(x) – 7.1213	0.5782
Test No. 2, Probe A-1	y = 22.549 Ln(x) – 13.203	0.7056
Test No. 3, Probe A-2	y = 21.934 Ln(x) – 17.881	0.9282
Test No. 4, Probe A-2	y = 24.875 Ln(x) – 17.229	0.9070

Figure 5



Regression analysis of six-minute averaged COM and triboelectric measurements.

Figure 6



Regression analysis of six-minute averaged Method 9 opacity and triboelectric measurements.

Given the above comparison relationships, COM readings appeared to be logarithmic in relationship to triboelectric signals, while Method 9 opacity observations were linear in relationship to triboelectric signals. These relationships can be better understood when the following observations are applied to the data:

- The relationship of opacity (particulate) in air is a logarithmic relationship as established by the Beer-Lambert Law (light penetration in a fluid). As emissions increase, opacity can never exceed 100%.
- The triboelectric system is more of a particle counter than a COM, and though both are measuring surrogate parameters for mass emissions, the particle counter is closer to a measurement of particles. Thereby, a logarithmic relationship could be expected based on the Beer-Lambert Law.
- The relationship of opacity to triboelectric signals is more linear at opacities below 40%.
- The triboelectric system programming can be set to focus on lower versus higher levels of particulates passing the probe. In the case of an EAF where the standard is basically no visual emissions (<3% opacity), the triboelectric system focus is directed toward low particulate concentrations.
- Method 9 opacity readings at 15-second increments eliminates much of the variability incorporated in COM measurements made every 0.5 seconds.
- The 5% band for visual opacity measurements also dampens the logarithmic nature of COM readings.

A review of the regression curves indicated several items with respect to the performance of triboelectric signal measurements when compared to opacity as measured by COM or Method 9.

- The slope of the linear regression curves for the respective plenum probes (A-1 to B-1 and A-2 to B-2) are very similar. This indicated that the dust introduced into the respective plenums was generating a similar response from the respective probes, even though there was dilution associated with the increased air volume as the dust traveled down the plenum toward the stack.
- The logarithmic and linear regression curves for the respective plenum probes, by location (A-1 to A-2 and B-1 to B-2), are similar. The probe relationships reflect the relative location of the dust introduction point, which is upstream of the B probe groups. This similarity in signal response from one plenum to another supports the reproducibility of the data and helps identify the location of the particulate introduction point.
- The logarithmic regression relationship of COM data and the linear regression relationship of Method 9 data are indicative of the system's linear performance in lower opacity ranges. This is expected for the EAF monitoring installation, because the system manufacturer configured it to monitor more effectively in the relative opacity range below 40%.
- The logarithmic correlation between higher COM opacities and triboelectric signals indicated that triboelectric signals, as a percent of scale, are relatively insensitive to opacities above 40%. Stated another way, triboelectric signals will vary proportionately to opacities below 40% with the scale setting used by the manufacturer for this comparison test. The triboelectric scale percent of 70 to 100% will indicate increases and decreases in opacity. However, the indication of opacities between 40 and 100% will be contained within the 70 to 100% triboelectric signal range.

Recognizing that low-level COM readings were not absolute (due to moisture interference) during the test comparison period on Nov. 16, but were related to increases or decreases in opacity, comparisons between COM and triboelectric signals showed very good correlation and reproducibility during this test period.

Comparison of COM and Triboelectric Signals during Normal Operations — As previously noted, problems were repeatedly experienced with the COM during the 45-day comparison period. Despite these problems, Ipsco determined to proceed with the comparison study using the originally scheduled period, recognizing that these problems were representative of actual circumstances encountered by EAF operators who attempt to operate a COM on the stack of an EAF baghouse.

Given the erratic behavior of the COM from Oct. 13 through Nov. 9, Method 9 observations were made during all daylight periods when the COM was indicating a six-minute average opacity of 3% or greater. This observation data indicated that there was only one actual period of six minutes with an average opacity >3% (4.8% opacity). However, the COM showed extensive periods of opacity >3% (9,300 minutes) during this period.

A review of the data indicated that the COM indicated false high opacities of >3% for a total of six days and portions of a day on three other days when no Method 9 observations supported these readings. The majority of these false high readings occurred during the period between Oct. 12 through 18, and could be associated with the initial calibration on Sept. 25. The inflated readings ceased after Oct. 18, when a recalibration and adjustment was done by a second technician. When surrogate particulate was introduced on Nov. 1, 2000, it was found that the COM was completely insensitive to that particulate introduction. It could be assumed that the 0% opacity readings, associated with insensitivity, began at or some time after the reprogramming performed by the manufacturer's representative on Oct. 18. The fact that Method 9 observations continued to indicate opacities <3% throughout this period (Oct. 18 through Nov. 1) provided a false sense of assurance that the COM inflation of opacities had been corrected. In fact, the COM was most likely blind for most of this period. This fact remained undetected, because the COM should have recorded 0% opacities, as did the Method 9 observers during this same time period.

The COM was again recalibrated on Nov. 6, 2000, and the unit continued to operate in a manner that better reflected actual emission characteristics throughout the period of Nov. 6-25. Some inflation of opacity was still a problem due to moisture interference. However, these differences were less frequent and corresponding Method 9 observations identified those nonrepresentative opacities indicated by COM measurements >3% opacity.

By comparison, the triboelectric signals were also tracked on a continuous basis. As a result of the surrogate particulate introduction tests, it was verified that the triboelectric system tracked both visible and invisible particulate. Therefore, to evaluate normal operation data some signal levels with an assigned significance had to be established.

In Ipsco's initial presentation of an operating and response system based on use of the triboelectric broken bag detection system to the U.S. EPA, several signal ranges were proposed. Arbitrary levels were picked for illustration in the presentation. However, for purposes of this comparison, it was necessary to better quantify those ranges. The signal ranges in Table 7 were used for summarizing data tracked by the triboelectric system. These ranges are for comparison purposes and do not necessarily reflect the final ranges that will be implemented by Ipsco for baghouse and broken bag detection system operation. During the time period of Oct. 12 through Nov. 7, the scale factor for the triboelectric signals was set at 200 picoamps. The percentages indicated in Table 7 are percent of scale as displayed and recorded by the triboelectric system computer and would typically apply to the scale factor of 200 picoamps.

For the A-1, B-1 probe groups during the time period of Oct. 12 through Nov. 7, there were several signal periods that exceeded the caution range (50 to 69%), lasting a total of 43 minutes. The alarm range for the A-1, B-1 probe groups was exceeded for a total period of six minutes during this time period. By comparison, the signals for the A-2, B-2 probe groups during the same period had a total time of 1187 minutes above the caution range, but had no signals in the alarm range.

There were no exceedances of the 3% opacity standard (as measured by Method 9) during this period, with the exception of one six-minute period on Oct. 13. The projected triboelectric signal ranges at the 200 picoamp scale factor were indicative of the actual emission performance of the baghouse.

The historic record of triboelectric signals was averaged for the plotting purposes. On a real-time basis, the system takes two measurements per second. However, the operator can select the averaging period that these measurements are plotted by the system. During the time period of Oct. 12 through Nov. 7, data were tracked and plotted using a six-minute average of measurements at the scale factor of 200 picoamps. At noon on Nov. 8, the averaging period was reduced to a one-minute average to allow for better comparison to Method 9 observations and COM tracking done during the particulate introduction tests conducted on Nov. 15-16. The scale factor was adjusted to 1500 picoamps on Nov. 8, to allow for better visual evaluation of the signals. The 1500 picoamp scale factor reduced normal signal activity to the bottom third of the operator's visual screen display. This visual change in real-time curve representation of triboelectric signals increased the operators ability to identify abnormal spikes quickly. The one-minute average and 1500 picoamp scale factor were used for plotting the data for the period from Nov. 8-25. For comparison of

Table 7

Proposed Signal Ranges for the Triboelectric Broken Bag Detection System

Normal operating range	0 to 49%
Caution range	50 to 69%
Alarm range	>70%

Table 8

Regression Curves under Normal Operating Conditions x = COM opacity (%) and y = triboelectric signal (% of scale)

Probe B-2	y = 1.479 x + 18.723
Probe A-2	y = 1.562 x + 14.806
Probe B-1	y = 1.0083 x + 31.33
Probe A-1	y = 0.71393 x + 31.735

Table 9

Signal Ranges for the Triboelectric Broken Bag Detection System for Each Probe Group

Probes group	A-1, B-1	A-2, B-2
Normal operating range	0 to 29%	0 to 24%
Caution range	30 to 37%	25 to 29%
Alarm range	>38%	>30%

normal operating data, a different set of normal, caution and alarm ranges needed to be established.

Given the linear regression analysis of the surrogate particulate comparison done on Nov. 16, those functions provided a basis for calculating an approximate triboelectric signal that is equivalent to 3% opacity. Using linear regression for the opacities below 40% provided a conservative margin for correlating triboelectric signals to opacity, whether measured by COM or Method 9 observations. The linear regression curves for the respective probe points are summarized in Table 8.

Using the four regression curves, the triboelectric signal ranged from 20 to 35% for all of the probe groups—as a percent of scale that is equivalent to 3% opacity. It is important to understand that the signal from the respective plenums groups (A-1, B-1 and A-2, B-2) are similar, but are different for the comparison period on Nov. 16. This is expected, because each plenum has a baseline triboelectric characteristic that is somewhat different. Each respective baghouse compartment provided a slightly different baseline particulate load when the EAF is operating, as was demonstrated on Nov. 16. This behavior is evidenced by the linear regression formulae. The slope for the A-1, B-1 probes is approximately 1.0, while that for the A-2, B-2 is approximately 1.5. The intercept for the A-1, B-1 probes is about 31 while that for the A-2, B-2 probes is about 16.

Given the slight difference in probe group readings with respect to COM opacity, data collected after Nov. 8 can be evaluated using relationships established during the surrogate particulate comparison conducted on Nov. 16. Recognizing that the triboelectric signals included both visible and invisible particles, an alarm range equivalent to 3% opacity was selected as indicated in Table 9 for the respective probe groups, and is applicable when using the scale factor of 1500 picoamps.

For the A-1, B-1 probe group during the time period of Nov. 8-25, there were several signal periods that exceeded the caution range (30 to 37%), lasting a total of 52 minutes. The alarm range for the A-1, B-1 probe groups was exceeded for a total period of two minutes during this time period. By comparison, signals for the A-2, B-2 probe group during the same period had a total time of 15 minutes above the caution range and had no signals in the alarm range.

When reviewing the data for the triboelectric signals it is evident that there was very little time when the triboelectric signals were in the alarm range. A total of two minutes was tracked on Nov. 22 when the triboelectric signals for the A-1, B-1 probes were above the alarm level of 38%. Method 9 observations and COM data indicated that opacity of the stack emission was below 3% for that operating day.

From this comparison study, it was determined that triboelectric signals are indicative of baghouse performance and compliance with a visual emission standard of 3% opacity. Furthermore, triboelectric signals allow operators to identify the baghouse compartment zone that contributes to increases in triboelectric signals while the baghouse continues to operate in compliance with its 3% opacity standard. Interface signal information from the baghouse PLC that controls the row sequence of bag cleaning allows the operator to identify the contributing compartment as well as the row of bags contributing to the increase of particulate being discharged to the exhaust plenum. Given this information, the operator can take corrective actions before the particulate contribution can contribute to a violation six minutes in length.

No such advance information is available to baghouse operators from COM or Method 9 stack exhaust plume observations. On the contrary, with the difficulty in maintaining a calibrated COM the operator must always consider the condition of greater than 3% opacity to be a false positive and investigate the COM before undertaking any meaningful corrective action on the baghouse.

Triboelectric signals remained primarily within the normal range selected for this evaluation, with some periods of signals increasing into the caution range and one short period when the signal exceeded the alarm level. Given that the alarm range and the associated caution range were based upon the respective regression curves for the plenum probe group, the regression curve appeared to predict the level of 3% opacity in a conservatively low manner. This provided additional assurance that the 3% opacity would not be exceeded if the study triboelectric comparison ranges were actually used for baghouse operation.

The time duration of the triboelectric signals may also be a factor in relating triboelectric signals to relative opacity. As both the COM and the Tribolink comparison rely on the size, quantity and structure of particles to make their measurements, the quantification of a time variable with respect to their relationship may not be significant. The triboelectric measurement includes particles that are invisible to a COM and therefore will always have a signal duration factor related to this invisible portion of particulate. No study work was done to specifically quantify any time-related variable between triboelectric signal and COM opacity. However, using a relatively short averaging period for the triboelectric signal will mitigate the difference in the duration relationship associated with the invisible particles. The one-minute averaging period used for the data tracked after Nov. 8 provided a real-time historical curve that was indicative of opacity measured by COM and Method 9.

EAF Steel Production During the Comparison Test — During the comparison period, EAF steel production continued in a normal fashion. Beginning with Oct. 12 through Nov. 25 (45-day period), steel was melted every day. As is typical of steel melting operations, the number of heats processed on a given day varied. The reasons for increased or decreased production vary due to a variety of factors. However, it is important to assure that production occurred in a representative fashion during this comparison period. Daily EAF and LMF melting records were collected and reviewed for the entire period of the comparison test. From this review, the meltshop's production during the comparison test period was concluded to be representative.

Findings and Conclusions

It is important to note that the data, correlations and formulae established for the Ipsco Steel, Montpelier Works baghouse are somewhat unique to the facility. The site-specific nature of particulate generated by an EAF is unique to that particular furnace and its fume collection and control system. Many variables effect the size, structure and quantity of particulate generated by a meltshop. These variables include: scrap type and charge practices, type of steels produced, length of heat cycle, slag practices, use of carbon and limestone, length of fume control duct, use of spark boxes, type of scrap preheating and type of offgas cooling.

General principles for the correlation and comparison of COM and Method 9 opacity to triboelectric signals are generally applicable to all EAF baghouses. Without evaluating this relationship in other EAF operations, and until such data are generated, it should be presumed that the specific correlation formulae between opacity and triboelectric signals will vary from shop to shop.

The findings and conclusions of this study are as follows:

- Both the COM and Tribolink systems tracked increases and decreases in baghouse particulate emissions.
- Both the COM and Tribolink systems are indicative of particulate present in the gas stream, although neither system is able to generate mass emission rates or concentrations in this application.
- The Tribolink system is able to detect changes in particulate levels that are invisible to COM, and as such can provide the baghouse operator information on the deterioration of bags long before the emissions become a violation of the opacity standard.
- The Tribolink system operated at the Ipsco Steel, Montpelier Works was configured by the manufacturer to focus on the lower opacity range of emissions, and this bias was observed during the surrogate particulate introduction periods. The Tribolink signals displayed a more linear relationship to COM opacity at opacity levels below 40% and were linear to Method 9 opacities observed during the comparison.
- During the surrogate particulate comparison, the Tribolink system response to opacities above 30 to 40% tended to be logarithmic in nature, and opacities as high as 80 or 100% would be tracked by the system as a percent of scale, with indicated levels still below 100% of scale. This does not appear to be a problem, because the NSPS for the EAF is a six-minute average below 3% and the system had a linear response characteristic with both COM and Method 9 opacities in this low range.

- Using the linear regression curves generated during the surrogate particulate comparison on Nov. 16, the triboelectric signal level associated with 3% opacity was predicted to be 25 to 30% of the scale when the scale factor was set at 1500 picoamps. Using the specific linear regression curves generated for the respective plenum groups, the data was evaluated against a range of signals that had an alarm range set at the predicted 3% opacity for the respective plenum group. Method 9 and COM data collected during normal operations supported these levels as indicative of the actual opacity of emissions.
- The comparison ranges of triboelectric signals used for evaluating the data from Nov. 8-25 showed that the Tribolink instrument was able to characterize the baghouse performance while still being indicative of compliance with the 3% opacity standard. The triboelectric signal was found above the alarm level for only two minutes on Nov. 22 during this comparison test. The COM and Method 9 observations on Nov. 22 did not indicate any exceedances of the 3% opacity standard. Therefore, it can be concluded that the regression curve predicted a 3% opacity, which is conservatively low when compared to actual opacity as measured by either COM or Method 9.
- As the Tribolink system probes were installed within specific zones of the discharge plenums of the baghouse, they served as a better indicator of the actual area performance for baghouse compartments where the particulate increases were originating. COM was unable to provide this type of area performance indication because of its stack location. The Auburn system ability to interface with the baghouse PLC further enhanced area identification capability of the Tribolink system. The Auburn computer/PLC interface can track the row and compartment of bags being pulse cleaned at any given time, and this information can be displayed with the alarm log data that indicated increased particulate above the programmed caution or alarm levels. This identification feature significantly improved the operator's ability to recognize and react to problems long before they become visible opacity violations.
- The Tribolink system generally allowed the baghouse operator to be proactive in response to changes in bag filtering performance as the system was able to identify increased particulates that are invisible to COM and Method 9 observers.
- Even with repeated calibrations by the manufacturer, it was difficult to get good performance from the COM for opacities below 5% during this comparison study. By comparison, the Tribolink system operated throughout the comparison period without additional manufacturer recalibration.
- The Tribolink system has the ability to modem interface with the manufacturer's home office. This feature was installed on the Auburn system at Montpelier Works. It allowed for trouble-shooting assistance to be accessed by operators within a matter of minutes during normal business hours. A modem interface for the COM is not a feature available for that instrument.

Triboelectric signals can be correlated to opacity, and particles of less than 1µm can be tracked by the system. Generally, the linear comparison function for triboelectric signals to opacity data is most directly applicable for opacities below 40%. This correlation range presents no problem for EAF baghouse operations that must comply with a 3% opacity standard. The Tribolink system provided a more precise and proactive tool for baghouse operators to maintain compliance with the zero visible emission standard imposed by the 3% opacity level.

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