White Paper

Triboelectric vs. Electrostatic Induction Bag-Leak Detection

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Triboelectric vs. Electrostatic Induction Bag-Leak Detection[1]

Introduction

This company introduced particulate flow detection, utilizing triboelectric (electrostatic charge) measurements, more than two decades ago. Recently, at least four additional vendors have offered similar products with varying degrees of sophistication. Due to the rapid increase in competition among vendors, inflated claims of performance with no supporting data has become all too common. In addition, increased performance has often been attributed to “new” technology explained in brochures with technical gibberish. In one case a vendor claimed a new probe sporting "charge induced eddy currents in an insulated super conducting probe". When pressed on the issue, the vendor reduced the claims to simple electrostatic induction (a technology understood 100 years ago). Another vendor has made claims of velocity independence with references to a well-established mathematical distribution while showing no math derivations or how the claims are supported by such references. Some vendors employ an AC triboelectric alternative to this companies DC version. Certain hazards conditions could develop when using the AC alternative if improperly applied.

Electrostatic mechanisms

The following is a summary of the known differences, advantages and disadvantages between DC triboelectric vs. AC electrostatic induction) particle detection methods for dust control systems:

Electrostatic measurements arise from several mechanisms. The triboelectric effect arises from particulate impacting a probe and transferring charge to (or from) the probe surface. In addition, a charged particle simply passing by a probe will capacitively induce a signal in a probe. This process is commonly referred to as electrostatic induction (1). These two mechanisms are described below:

The Triboelectric Effect

Triboelectric charging or frictional electrification, the transfer of charge as two materials contact or rub against each other, has long been known and has been characterized for many materials. The triboelectric phenomenon is complex and is a function of several mechanisms. Factors that contribute to charge transfer between contacting materials include material work function, velocity and surface roughness, adsorbed gasses (like moisture), particle concentration and size, and pre-existing charge. The signal, which arises from the charge transferred to the probe by particulate impinging on the probe surface, is a function of several factors as indicated in the equation below.

$$i = \frac{kMv^n}{D} + QC\frac{M}{D_3} \qquad [1]$$

k = proportionality constant unique to material
M = mass flow (concentration x volumetric flow rate)
D = average particle diameter
v = particulate velocity

n = exponent unique to material (usually 2)
Q = charge on contacting particles
i = triboelectric probe current to ground, (signal)
C = proportionality constant

Under many production conditions, such as in transfer lines, many of these factors including velocity are constant. Under such circumstances the signal will be proportional to concentration and may be used as a rough indication of mass flow. Under conditions of varying velocity, the signal is often observed to change as the square of the velocity. Therefore, for mass flow measurement, utilizing electrostatic particle detection, a separate real-time velocity component should be incorporated in the mass-flow algorithm, whereupon correlation with another detection method can be performed.

Electrostatic Induction Effect

Electrostatic induction requires that sensed particulate are pre-charged (neutral particles cannot be sensed). As a charged particle passes by a probe (that may or may not have an insulating coating), a mirrored charge movement is induced in the conductive probe material. If, for example, a positively charged particle passes the probe, a negative charge will enter the conductive probe material. After the particle leaves, the mirror charge will pass back out of the probe. The net effect is a small positive and then negative current measured by the probe circuitry. (Fig. 1)

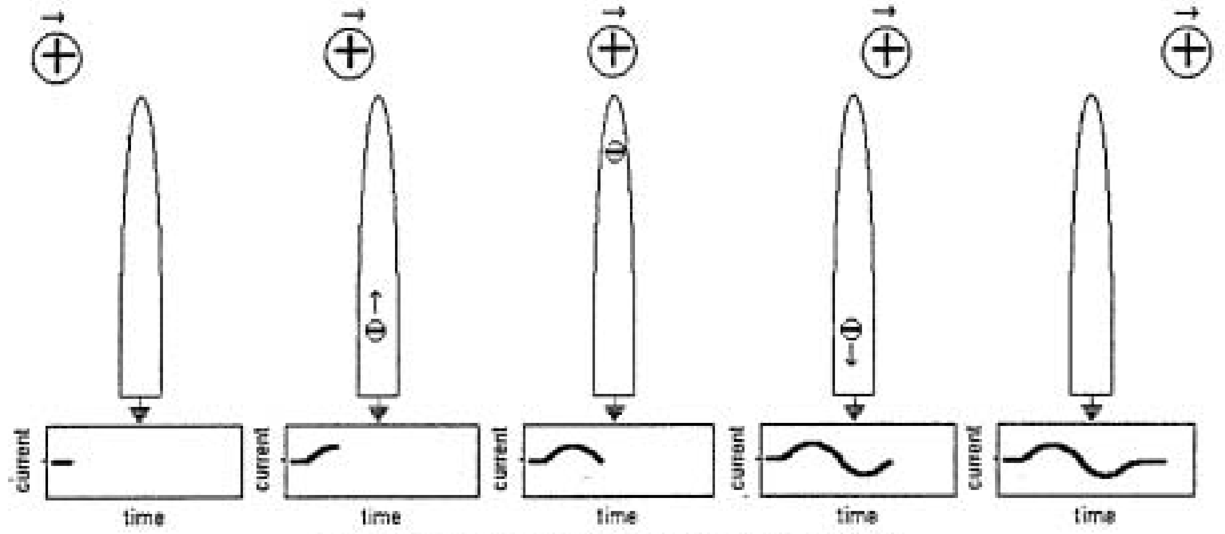

Figure 1. Electrostatic Induced Current

Which Mechanisms Apply?

The electrostatic induction mechanisms (AC) will apply in all cases if particles contain pre-existing charge. The triboelectric effect will apply in cases where particulate actually contact the probe surface. One vendor makes the claim that the electrostatic induction mechanism "is the dominant interaction with small (<l.00 micron) particles". This is not true. We have performed particle size experiments utilizing

our in-house, experimental, Flex Kleen dust collector and found that the triboelectric effect is dominant in particle sizes at least down to 0.3 micron, with velocities greater than 1000 feet per minute.

Traditionally, probes have been supplied with an exposed conductive surface. Inductive (AC) probes require an insulated surface. The insulated surface tends to block DC currents caused by the triboelectric effect and pass the AC currents from the electrostatic induction effect. Two claimed advantages are a resistance to offsets caused by moisture (or conductive materials) and better signal linearity with concentration. We contend that the un-insulated probes that permit direct measurement of the DC current induced by the triboelectric effect provide a much more accurate means of particulate measurement, due primarily to the DC signal dominance. Although there are certain conditions when the insulated probe and AC signal measurements excel (below 1000 feet per minute), our information supports the general advantages of the DC measurement, particularly in terms of higher sensitivity and linearity. Furthermore, if the required, AC system, probe insulation erodes or corrodes (not unusual in this environment), the AC signal will deteriorate or fail.

Exposed Metal Probe DC and AC Measurements

We compared the performance of DC and AC circuits with particular emphasis on the effect of velocity variation. Figure 4 shows a typical example of the signal from an exposed metal probe. Note that the signal contains both a DC (non-zero) component and an AC component (the up and down jitter).

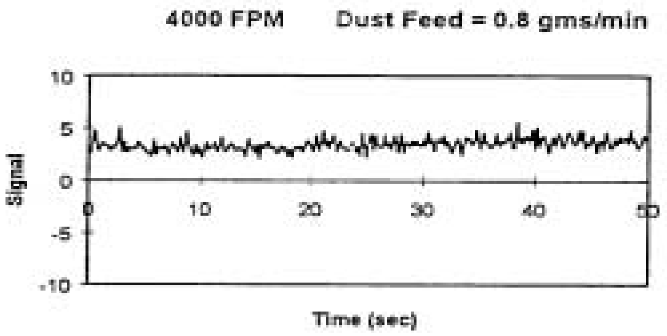

Figure 5 shows the results for both the DC and AC components of all experiments. It should be noted that circuit & sensor noise will contribute to the AC component of the measurement. Measurements made at zero mass flow showed the AC noise component of the signal to be less than 1 X 10-4 in all of the subsequent plots. Each plot shows signal versus mass flow for a given velocity. Note that the AC component has been multiplied by 10 to place it on a similar vertical scale.

Note that all the AC plots show an increasing signal with feed rate, however, the plots are not linear and do not extrapolate to zero signal at zero feed rate. These data imply that AC signals on exposed metal probes will indicate some change in mass flow rates but they should not be thought of as quantitative.

The DC plots in Figure 5 for 1000 FPM shows almost no response while the data for 2000, 4000, and 8000 FPM are extremely linear and all extrapolate to zero at zero concentration. These data imply that DC signals on exposed metal probes not only indicate changes in mass flow, but they may be thought of as quantitative under conditions of fixed velocity over 1000 FPM.

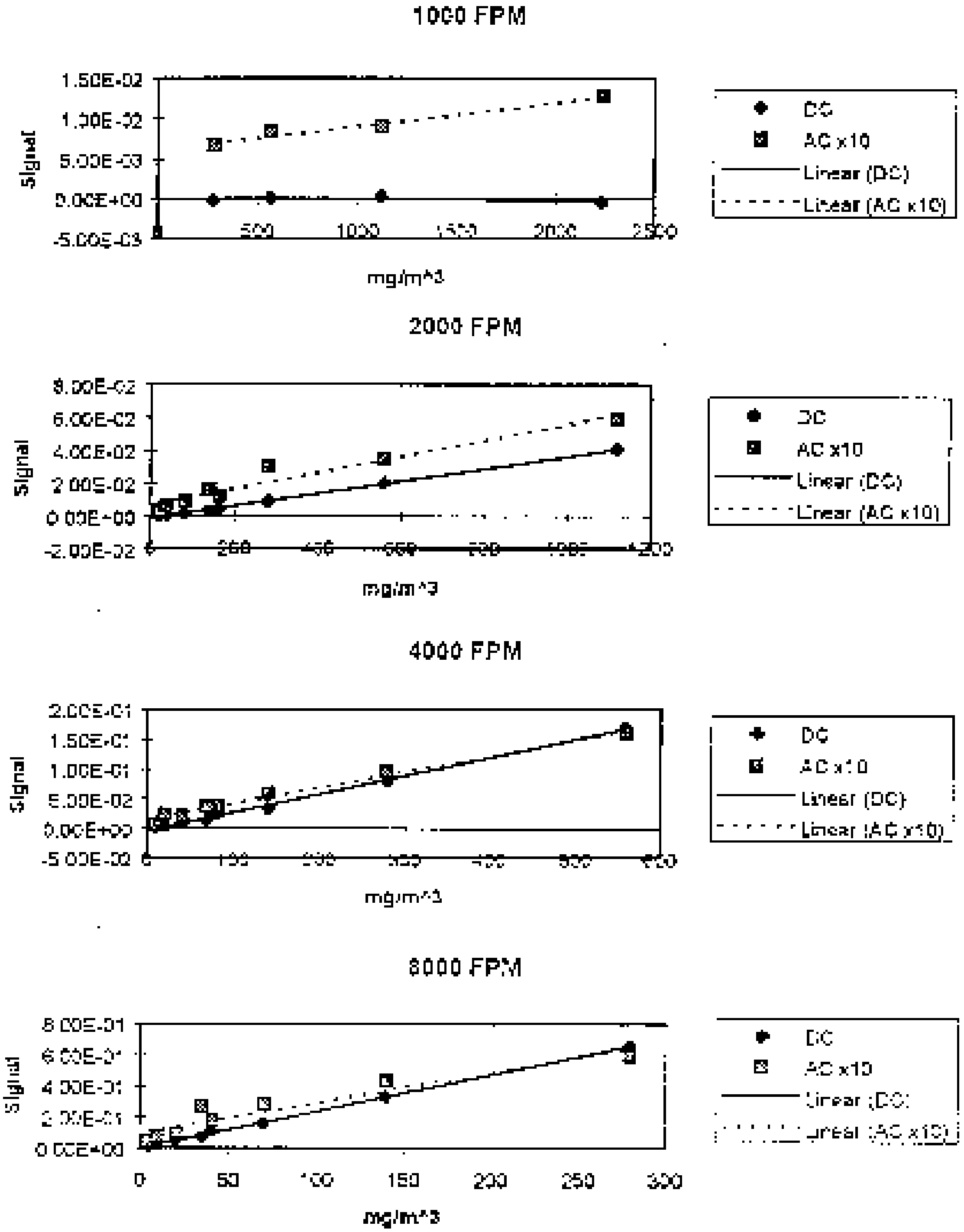

Figure 5. DC and AC Signals versus Feed Rate (at fixed velocities)

Figure 6 shows the effects of velocity on the DC and AC signals with a constant mass flow. The DC component follows the well-documented velocity squared relationship. Interestingly, the AC follows a similar relationship. This directly contradicts one manufacture's claim that the AC signal actually goes down with an increase in velocity due to the decrease in concentration. This phenomenon will be discussed again later with insulated probes.

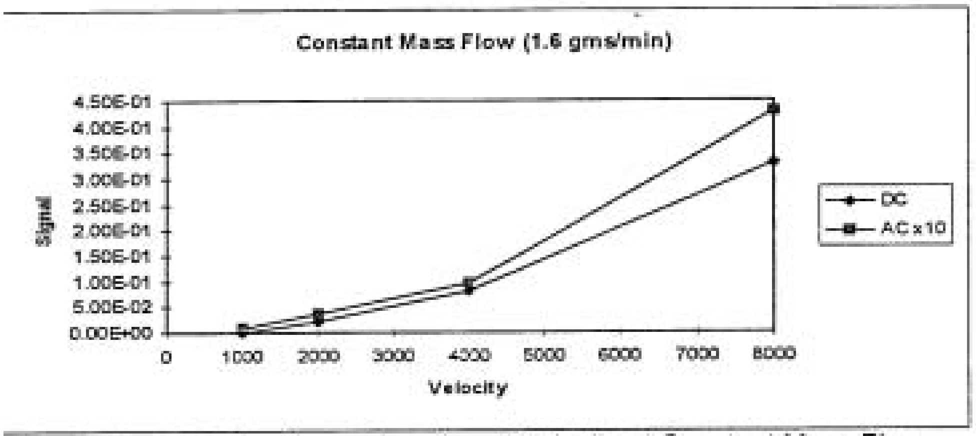

Figure 6. Signal as a Function of Velocity at Constant Mass Flow.

Insulated AC Probes

Similar experiments were carried out on a Teflon insulted probe. As previously mentioned, the DC current is blocked and only AC is measured. Figure 7 shows an example of the collected raw data with no DC component.

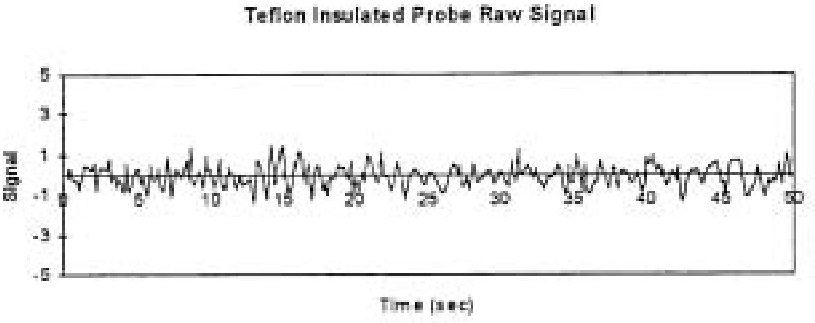

Figure 7. Teflon Insulated Probe Raw Signal

It is important to realize that DC triboelectric effects do still occur. As particulate hits the probe, the insulator surface will build up a voltage, which in some cases is extremely high and could be hazardous (see below).

If anything about the flow condition changes, such as concentration or velocity, the total charge on the insulator surface will change. As this change occurs, an apparent DC component is induced. Figure 8 shows an example of data from the Teflon insulated probe during a velocity reduction and subsequent increase. The negative and then positive offsets are readily apparent as the total surface charge is modified.

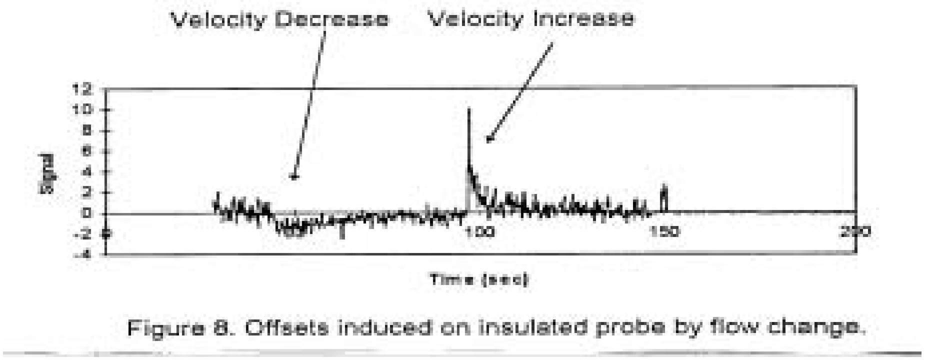

Figure 8. Offsets induced on insulated probe by flow change

Such offset changes on a fast time scale produces an AC signal component. Figure 9 shows an example of the AC amplitude (or magnitude) versus time as velocity is increased in steps. Note the excess signal anomalies that occur every time the flow increases. One concern about using the insulated probe technique in rapidly varying flow conditions is the introduction of temporary non-representative offsets.

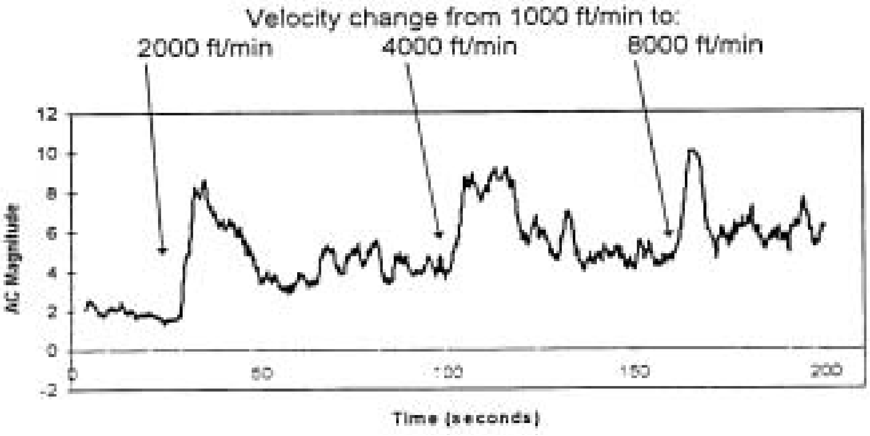

Figure 9 AC Magnitude During Stepped Flow Velocity

With this in mind, data was taken at a variety of conditions, each time waiting about 30 seconds for the AC signal to stabilize. Figure 10 shows a summary of the data in several plots, each under conditions of' constant velocity. Concentrations ranged from 3 to 2300 mg/m^3.

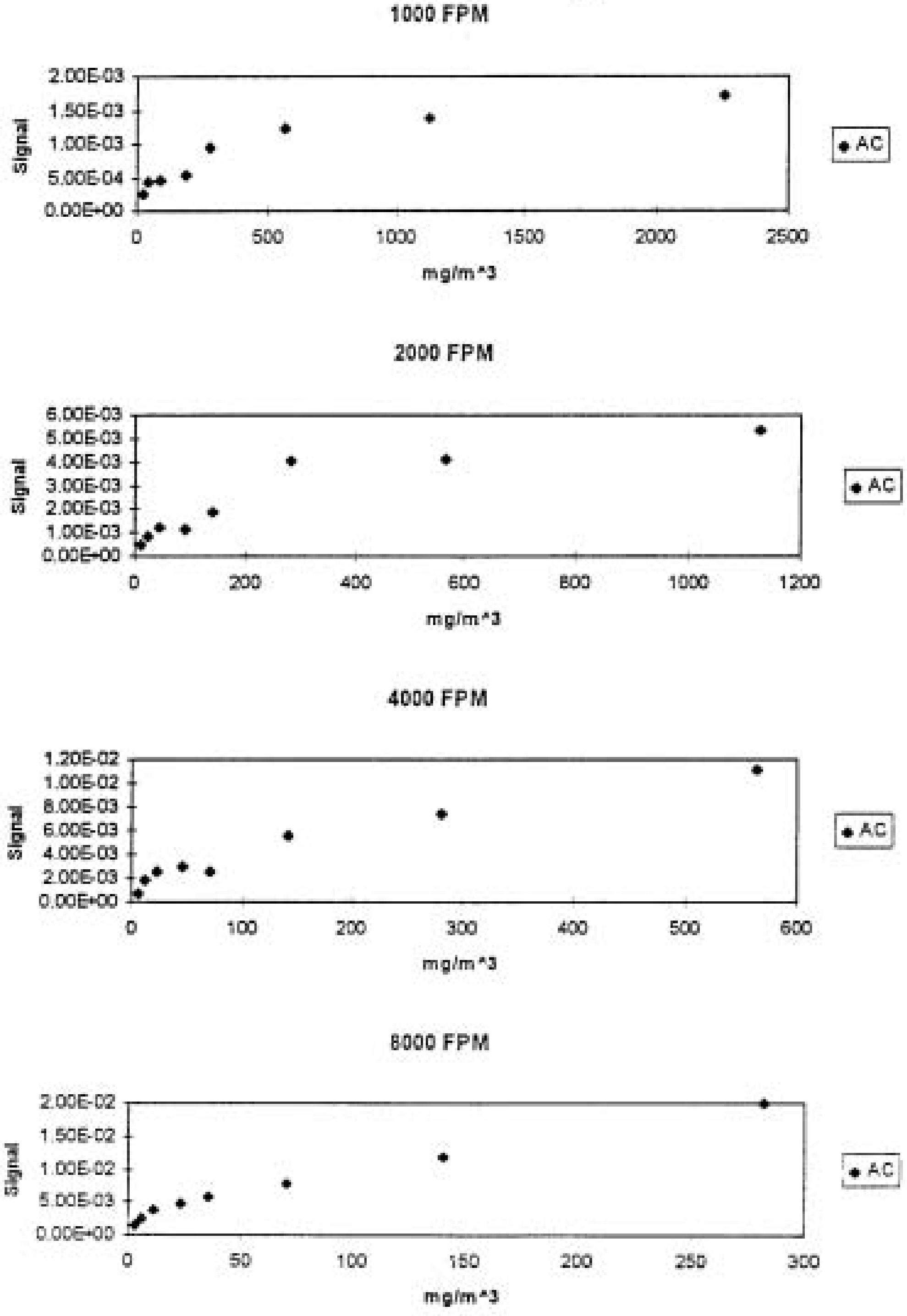

Figure 10. Insulated Probe AC Signal vs Concentration as Constant Velocities.

In general the insulated probe AC response is quite non-linear with concentration (or mass flow) at constant velocity. There is a general loss in sensitivity to concentration at higher concentrations, i.e. a flattening of the curves in Figure 10 to the right on the plots. Figure 11 shows an expanded view of the 8000-ft/min plot (in Figure 10) at low concentrations. The non-linear response is still apparent at this scale. However, it appears as if the response may be fairly linear below about 5 mg/m^3.

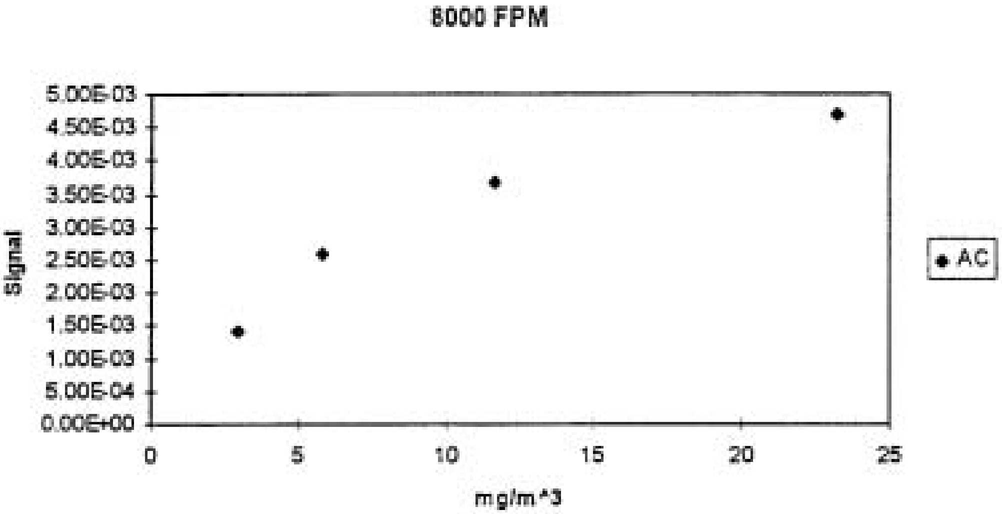

Figure 11. Insulated Probe Response at Low Concentrations

Important Issue

The charge imparted to the surface of an insulated probe due to the impacting of particles (triboelectric effect) in a moderate to high velocity gas stream could become an ignition source if the gas contains a hazardous material. If the gas stream is very dry and the particles contained within it are nonconductive, the charge on the surface could reach a very high voltage. For a fixed set of physical conditions, the energy available from the charge is proportional to $V^2/2$, thus requiring careful review of the operating conditions when installing an insulated probe. This potential hazard has been independently tested and verified (Appendix A).

Auburn occasionally employs jacketed (insulated) probes for certain difficult applications wherein moisture or conductive particulate could electrically bridge the insulator of a noninsulated probe. However, under either of these conditions the moisture or particulate provides a leakage path to ground (Earth), thereby preventing excessive charge build-up on the jacket of the probe. The vast majority of dust collection environments are non-conductive and relatively moisture free, requiring no probe insulation—thus eliminating the potential for incendiary charge build up. We recommend intrinsically safe, DC triboelectric systems for those applications where potential ignition hazards exist (Appendix B).

Summary

The DC probes exhibited far more linearity and quantitative type responses, while AC probes were suitable only for flow velocities of 1000 ft/min or less. For a majority of bag house applications the DC probe will function better because of the linear response under constant velocity, and since velocities in these applications are generally above 2000 ft/min, the electrostatic method has proven to be more reliable. If mass-flow measurement is required in velocity variable particulate flow streams, we recommend continuous velocity correction. Velocity compensation is not applicable for AC/inductance particle detectors, due to non-linearity in response to velocity variation. The only other compensation method for AC inductance systems, when the flow stream velocity is inconsistent, would require daily, Method 5 recalibration.

[1] Based on original Auburn experiments conducted in 1999

Appendix
A

Chilworth
Technology

A Professional Process Safety Firm

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ELECTROSTATIC TESTING

OF

STEEL ROD

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FOR AND ON BEHALF OF CHILWORTH TECHNOLOGY, INC
Report # : R/3748/0302/YD
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INTRODUCTION

A sample was received from **Auburn Systems** for purposes of electrostatic testing. Testing on the sample included measurement of breakdown voltage and propensity for propagating brush discharges. This report provides: (1) relevant background information; (2) a description of the test methods employed; and (3) a summary of the test results.

BACKGROUND

Propagating brush discharges are highly-energetic electrostatic discharges capable of igniting many flammable atmospheres including dust clouds. These discharges -- exhibiting effective energies of as much as several Joules -- derive their energy from the formation of a double layer charge on both sides of a thin surface, such as a fabric or film. A double layer charge forms when the charge on one side of an insulating surface is sufficiently strong so as to induce an equal and opposite charge on the other side by atmospheric ionization. Propagating brush discharges may occur when the double layer charge is exposed to plant, equipment, or personnel.

Only materials possessing a certain dielectric strength are capable of supporting the double layer charge needed to produce propagating brush discharges. The measure of dielectric strength relevant to propagating brush discharges is breakdown voltage. Breakdown voltage refers to the point at which the insulating property of a material breaks down upon application of high voltage. Breakdown voltage can be used to evaluate the propensity for a material to produce propagating brush discharges.

METHODS

Breakdown Voltage Determination

Breakdown voltage testing was performed in accordance with German Standard DIN 53,481 (VDI 0303) and ASTM D3755-97. The sample was warped up with aluminum very tight and the end was connected with grounded wire and a cylindrical electrode connected to a high voltage power supply was placed on top of aluminum. The voltage to the electrode was increased gradually until the insulating property of the sample broke down and a large current passed through to the grounded plate. The voltage at this point -- the breakdown voltage -- was recorded.

Breakdown voltage testing was performed at several locations on the sample, on all sides of the sample, and under both ambient and low humidity conditions. For low humidity testing, the laboratory was maintained at less than 20 percent humidity and the samples were conditioned at less than 20 percent humidity for 12 hours prior to testing.

Propagating Brush Discharge Testing

One end of sample was connected with grounded wire and sample charged using a corona probe connected to a high voltage power source. Attempts were made to produce propagating brush discharges by steadily approaching the charged sample surface with a grounded spherical electrode.

Propagating brush discharge testing was performed on all sides of the sample, and under both ambient and low humidity conditions. For low humidity testing, the laboratory was maintained at less than 20 percent humidity and the samples were conditioned at less than 20 percent humidity for 12 hours prior to testing.

RESULTS

The breakdown voltage of the sample was 19.5 kV under ambient humidity and 23 kV under low humidity conditions. Notably, only materials having a breakdown voltage of 4.0 kV or greater have been observed to give rise to propagating brush discharges when highly charged.

Very low energy propagating brush discharges were observed from the sample under the test conditions. The energy of the discharges may have been limited by the voltage applied to the sample using the carona. Thus, more energetic and incendiary discharges may be expected under higher electrostatic charging scenarios in the field.

<u>TABLE 1</u> BREAKDOWN VOLTAGE MEASUREMENT

Sample Information

Company Name	:	Auburn Dechene
Test Material	:	Steel Rod
Reference Number	:	N/A
Sample Origin	:	N/A
Comment	:	Steel stick covered with polymer

Test Information

Test Purpose	:	To measure the breakdown voltage of a sample.
Apparatus	:	High Voltage Power Source Cylindrical Brass Electrode, Grounding Electrode
Test Date	:	03.21.02 – 03.22.02
Analyst	:	Y. Dai
Ambient Humidity	:	41%RH, 21°C
Low Humidity	:	15%RH, 21°C

Results:

Breakdown Voltage (Maximum of Measured Values)	:	**19.5 kV @ Ambient; 23 kV @ Low Humidity**

Trial	**Ambient Humidity (kV)**	**Low Humidity (kV)**
1	19	20
2	19.5	19
3	19	8.5
4	17.5	22
5	18	23
6	19	23
7	19	20.5
8	17	20
9	18	19.5
10	17	18

TABLE 2 PROPAGATING BRUSH DISCHARGE TESTING

Sample Information

Company Name : Auburn Dechene
Test Material : Steel Rod
Reference Number : N/A
Sample Origin : N/A
Comment : Steel stick covered with polymer

Test Information

Test Purpose : To attempt to produce propagating brush discharges from an electrostatically charged sample.
Apparatus : Corona Charging Probe, Grounding Electrode
High Voltage Power Source
Test Date : 03.22.02 – 03.25.02
Analyst : Y. Dai / V. Ebadat
Ambient Humidity : 41%RH, 22°C
Low Humidity : 18%RH, 25°C

Results:

Propagating Brush Discharges: **Positive**

Comment: Low energy propagating brush discharge was observed

Trial	Ambient Humidity Propagating Brush Discharges?	Low Humidity Propagating Brush Discharges?
1	Yes	Yes
2	Yes	Yes
3	Yes	Yes
4	Yes	Yes
5	Yes	Yes

Appendix
B

Intrinsic Safety

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Auburn Systems
4-23-01

Introduction:

All Auburn TRIBO.Series dust detectors are designed to operate safely in hazardous environments and comply with the following design guidance standards: EN 50-014 / EN 50-020, CSA STD C22.2 No. 142-M1987 & No. 157-92, FM Class 3600 & 3610.

Basic Design Concepts Employed:

- Use of an infallible power (mains) transformer to insure that no more than 30 vrms can appear in the low voltage circuitry of the instrument.
- Inclusion of a fused redundant Zener diode barrier to insure that an excessive voltage can not appear in the low voltage circuitry of the instrument due to the application of a foreign voltage at the 4-20mA output terminals.
- Where a relay output is installed, installation of a relay that provides adequate coil to contract spacing and isolation.
- Installation of an infallible current limiting resistor in series with the sensor connection terminal as an integral part of the encapsulated front-end module.
- Inclusion of a permanently connected Over Voltage Protector at each sensor probe to prevent excess voltage build-up on the probe, if the electronics should become disconnected.
- Maintain adequate creepage and clearance distances on circuit boards.

Infallible Transformers: Signal Transformer Co. Part Number 14A-10R-28, Part Number 14A-56-28 both of which are Type B construction with completely separate and consolidated primary and secondary winding, thus providing 4000 vrms primary to secondary isolation. These transformers also pass the 1.5 X fuse current rating temperature rise test required for qualification as infallible component.

Another smaller transformer is used depending on the product enclosure size and is a modified version of Signal Transformer Co. Part Number 14A-5.0R-28. Although the VA rating of the standard transformer is adequate for the application, the smaller wire size used in the primary caused a higher than acceptable temperature rise during the 1.5 X fuse current rating temperature rise test. For this reason, Signal Transfer manufactures a custom version of the transformer, with a single primary winding incorporating an integral thermal fuse, for us with a special Part Number 14A-5.0R-1274 (for 115/120 v operation) or Part Number 14A-5.0R-1315 (for 230 v operation).

Barriers at 4-20mA Outputs: All output barriers use a redundant (parallel pair) of 16 volt 5 watt Zener diodes and a fast acting 1/16 A (63mA) 250-v fuse. This ensures that no more than +16 volts or -.06 volts can enter the low voltage circuitry, due to a foreign voltage at the output terminals. Each diode will individually withstand a continuous current of more than 3 times the fuse current rating, thus assuring that the 1^2T of the diode will always exceed that of the fuse. Also, an infallible current limiting resistor is included to insure that the current breaking capacity of the fuse cannot be exceeded.

Output Relay: For certain models with output relays, American Zettler Number AZ 2732-053-52 which provides 4000 vrms isolation between the coil and contacts, is used.

Infallible Current Limiting Resistor: An infallible resistor must be constructed such that no failure mode (usually burnout) cannot cause it to short circuit or become more conductive. An infallible resistor must also have a continuous power rating of at least 1.5 X the power that it would dissipate, should the sensor connection be shorted to the ground and a circuit fault cause line (mains) voltage to become present at the resistor.

A 150K ohm, 0.5w, MIL type RL20 resistor is included in the encapsulated front-end module for each sensor connection. The resistor meets the aforementioned requirements, protects the input circuit from voltage spikes and the encapsulation insures isolation of the sensor connection from comprise by other voltage sources.

Over Voltage Protector (OVP): During normal operation, the sensor probe is maintained very near ground (earth) potential (<0.1). If the ground (earth) return path for the sensor probe is broken by removal of the electronics from the housing or the disconnection of the coaxial cable, a static charge could accumulate on the probe. If a remote sensor is involved, the coaxial cable could become charged as well. Such a situation could be an ignition hazard, unless the maximum voltage is limited to a safe level. All sensor probes are provided with on or more gas discharge OVP's that will conduct to ground (earth) and limit the probe voltage to ~ 90 v. Also, the special coaxial cable used for remote sensors is designed with a resistive center conductor thereby limiting the discharge current to a save level should the cable become damaged at any point in its length while charged to 90 volts.

Creepage and Clearance Distances: Generally, a minimum of 6mm clearance and 10mm creepage distances are maintained where required. However, in some cases, the 10mm creepage requirement becomes impossible to maintain on the circuit board. To resolve this problem, a grounded (earthed) and non-insulated guard conductor was interposed.