SOUTHCORP CLEAN AIR SYSTEMS
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EXTENDED TRIBOELECTRICS

Introduction

This document explains the application of the triboelectric effect in industry, in detail. Please also refer to Basic Triboelectrics.

Triboelectric Technology

The Emission Signal

This chart illustrates a typical emission signal, it's mean (DC component), and standard deviation (AC component), shown as a +/- band around the mean.

AC Coupling And DC Coupling

It is important to distinguish between traditional DC COUPLED Triboelectric Emission Monitors (which measure the mean value of the current in the probe) and AC COUPLED emission monitors which measure the perturbations of the current signal around that mean value. In a DC coupled emission monitor, the mean value is measured by simply filtering out the perturbations and measuring the DC value of remainder (which is usually a voltage signal at that point). In an AC coupled emission monitor, the signal is processed by a HIGH PASS filter to remove the mean value, leaving the perturbations, which may be measured or DETECTED by a number of means including average-value, peak, RMS, or various hybrids. Of these, only RMS detection truly measures the standard deviation of the signal, and this document will in general use the term STANDARD DEVIATION to refer to the measurement of this signal in an AC coupled emission monitor. For noisy measurements such as emission monitoring there is little practical difference between the various AC methods, and the same comments apply equally well if another method is used.

Limitations Of DC Coupled Technology

From the foregoing, it is clear that DC Coupled Emission Monitors suffer from a number of potential problems:

The sensitivity of a DC coupled emission monitor can approach zero because the mean charge transferred by particles colliding with the probe will be near zero if...

- the probe is partially coated with dust, or
- the probe material is compatible with the dust, or
- the exposed materials vary, leading to both + and - charged particles, or

- the probe is coated with an insulator (blocking DC current), or
- the particles have reached equilibrium with the duct.

Although any of the above can cancel the mean signal and render a DC coupled emission monitor non-functional, the inherent randomness of the signal guarantees that there will always be a measurable AC signal.

DC coupled emission monitors are unsuitable for many corrosive environments, as a PTFE or other insulating coating cannot be used on the probe.

DC coupled emission monitors must be cleaned regularly to remove particulate buildup whereas AC coupled emission monitors can typically cope with particulate buildup of 10mm thickness or more without losing calibration.

With excessive conductance across the insulator, a DC coupled emission monitor's output can be unpredictable (may go very high or very low depending on it's input offset voltage at the time. By contrast, an AC coupled emission monitor will fail predictably by losing signal (and generally initiating a low level signal alarm). All triboelectric Emission Monitors will generally tolerate light bridging of the probe's insulator by a conductive coating, without loss of accuracy.

DC Coupled Emission Monitors measure only a small cross section of the dust flow (which may not be representative of the dust flow across the remainder of the duct), because they respond only to particles actually colliding with the probe. For a similar coverage, a DC coupled emission monitor requires a much larger and more obstructive probe than an AC coupled Emission Monitor.

DC coupled Emission Monitors have a poor SIGNAL-TO-NOISE ratio, and hence exhibit poor performance at very low signal levels. The performance of a measuring device is often limited by it's signal-to-noise ratio. For a DC coupled amplifier, the noise comprises all the DC errors in the device's amplifiers, including offsets, thermal and long-term drifts. In the very best modern amplifiers, these DC errors may be as low as 20 microVolts. However for an AC coupled amplifier the noise sources are 1/F noise, Johnson noise and a few less obvious noise sourcs, which in total seldom exceed 1 microVolt over the relevant frequency spectrum. When the signal level drops to the same level as the noise, it is no longer possible to distinguish the signal from the noise, so this noise level sets a lower limit on the signal levels that can be detected. This is the main reason that even under ideal conditions, the best modern AC coupled sensors including emission monitors are of the order of 10 times more sensitive than their DC counterparts.

Market Perceptions

In spite of the above, applications remain in which the parameters are sufficiently predictable as to allow the use of a DC coupled Emission Monitor without problems. All of these applications, however, are equally well served by an AC coupled emission monitor, so there is no compelling argument to support the retention of DC coupled technology, when AC coupled technology can more easily cope with those applications, and a great many more.

Unfortunately, the inappropriate use of DC coupled emission monitors has given rise to unfair condemnation of triboelectric technology in general. A better understanding of the differences between these two technologies will, it is hoped, dispell such false perceptions.

Emission Monitor Structure

Both AC and DC coupled emission monitors require a number of stages of amplification, coupled together by filters which pass only the required signals, excluding unwanted frequencies. A DETECTOR then processes the amplified and filtered AC signal into a high level DC signal, which is either transmitted as 4-20mA, or further processed in a microprocessor, and transmitted via a digital network. The total combination of all these issues produces a certain characteristic which is often given a specific name; the characteristic adopted for the EMSn and EMPn series emission monitors is termed TRIBO-KINETIC.

The coupling method (AC or DC) is unrelated to the power supply method (AC or DC voltage) or to the signalling method (AC carrier, DC voltage, DC current or digital network). For example, EMS6 employs AC coupling, DC power supply and digital network signalling.

AC Induction

Basic Principles

While particles striking the probe produce both a mean (DC) value and perturbations (AC), particles passing near the probe also produce an AC (but no DC) signal in the probe by way of induction. This induced AC current can easily exceed the AC component of the direct-collision current, and is considered the primary signal measured by an AC triboelectric emission monitor.

Behaviour Of A Single Particle

As a single charged particle approaches a probe, the electric field strength between the particle and the probe increases, which induces an increasing displacement of charge in the probe. Changes in this charge displacement are measurable as probe current. As the particle passes by without touching, the separation distance reaches a minimum when the particle is exactly beside the probe, by which time the charge displacement is at it's maximum, and the measured current has dropped back to zero. As the particle moves away, the charge displacement drops back towards zero, and an opposite polarity current pulse is measured. This is illustrated in the following chart, which was generated by plotting the physical equations...

Signal Variations

Each particle induces a similar BIDIRECTIONAL DOUBLE CURRENT PULSE, but the sharpness of the shape, amplitude and timing depend on the charge on the particle, it's velocity and it's trajectory. Trajectory varies entirely according to the geometry of the duct, while charge density and velocity distributions are statistical, and might look like the following charts...

AC Signals Are Predictable

A steady flow of very light particles will tend to follow the streamlines closely. Further, if the particles are all identical perfect conducting spheres, all interactions will be similar and they will all tend to accumulate the same charge. Under all these ideal conditions, the standard deviations of the velocity and charge will be much smaller than the more typical examples above, so the BELL CURVES will be much narrower, and the total probe signal will be composed of the sum of a large number of similar impulsive events. Even then, however, trajectories vary with the geometry of the duct, charges, velocities and trajectories are all UNCORRELATED, and the charge collection process in inherently random. These things guarantee that the standard deviation of the sum of these individual events will be a predictable, measurable NOISE (although the mean over any long period will be zero, which is why DC coupled Emission Monitors do not respond to induced charge).

AC Signals Even Better In The Real World

In a real situation, the particles are not spherical and the geometry of their interaction with the air and other solids varies, causing more overall variation, and slightly more signal. If the particles are not conductive, their surface charge will not be uniform, again increasing the variations and signal strength. If the particles are either more dense or larger they will tend to cycle through vertical movements due to gravity and collisions, again increasing the variations and signal strength. All these effects simply increase the sensitivity of an AC coupled emission monitor.

Parameters

The effectiveness of a Triboelectric Emission Monitor depends on a number of parameters. In most industrial processes these parameters are well controlled, and hence the output from the emission monitor will also be consistent. However when one or more of these parameters varies substantially, the emission signal may also vary. The user generally need not be aware of any of these parameters. However there are some situations where the user should be aware of their potential impact, in order to obtain optimum accuracy from the Emission Monitor. The following explanations are intended for those situations.

Material

Each material has a unique position in the triboelectric series. When two materials interact, the signal generated is related to their separation in the triboelectric series (above). In the case of Triboelectric Emission Monitoring, the particulate matter contacts the duct, the filter medium, the gas and the probe, and all these interactions affect the final signal. Processing of a material, particularly combustion, affects the physical properties of it's surface such as hardness, flatness, malleability, etc, all of which affect the way in which a particle interacts with other material. Furthermore, most processed particulates are heterogeneous, so the composition of the surface may differ from that of the interior. All these factors can modify the basic triboelectric properties to some extent. Virtually all materials will work (eg alumina, coal dust, drugs, glass beads, metals, silica, talc, etc), however the sensitivity of the Emission Monitor may vary over a range of 5:1 or more as the material varies.

Mass Flow Rate

Emission values may be displayed in any required units, however the more material passes a conventional Emission Monitor, the higher will be it's output signal, so the natural units are mass flow rate (eg mg/s or kg/hr). An emission signal calibrated in mass flow rate units can be totalised over a period to produce the total mass emitted over that period (TotalMass = MassFlowRate X Time). Also, a mass flow rate signal is independent of any excess air introduced, or of the gas temperature or pressure. For example, if the gas stream were doubled in volume by dilution with an equal volume flow of air, or halving the pressure, or doubling the absolute temperature, then the velocity would double, the particulate mass density would halve, but the Emission measurement would remain constant as it should. In summary, then, a Triboelectric Emission Monitor indicates particulate emissions as a mass flow rate, and when using those units, the signal will be relatively immune from the effects of velocity, temperature, pressure and excess air, and can be averaged or summated meaningfully over a period of time.

Mass Density

Many users, however, prefer to display instantaneous particulate emissions as mass density (eg mg/m3) rather than mass flow rate, because such measurements can be more meaningful as the load varies, and because Environmental Protection Agencies often specify mass density criteria. Triboelectric Emission Monitors are therefore commonly calibrated in such units, and when gas velocity varies only a little, as in most plants, this calibration will remain valid. In reality, however, MassDensity = MassFlowRate / (Velocity * DuctArea), or mg/m^3 = mg/s / (m/s * m^2). Duct area is a fixed factor, but to obtain mass density it is necessary to divide by velocity, so mass density is seen to be sensitive to velocity. If the gas velocity varies substantially from the velocity at calibration, the perceived sensitivity as mass density will vary, and summations over time will become less meaningful. If the emission output is required as a mass density, CONNECT 2.20+ software includes a function to compensate the emission signal so it correctly indicates mass density as velocity varies, using an external measurement of velocity, or an indicative signal such as inlet airflow measurement, load demand, etc.

NTPO

Changes in temperature, pressure and excess air cause no loss of accuracy in a mass flow rate emission signal. However these parameters will affect a mass density emission signal. To counter this sensitivity, there is an increasing trend towards "normalising" emission measurements, for example to indicate what the mass density would be if the conditions were changed to "NTPO" (normalised temperature, pressure and Oxygen; eg 300degK, 1 atmosphere and 0% or 5% excess air). Calibration is unaffected by these parameters. However, if the isokinetic test results are normalised (usually by a manual calculation), then the Emission Monitor output should also be normalised, if it is to be valid. CONNECT 2.20+ includes this function (not needed for mass flow rate signals).

Sensitivity

AC coupled Triboelectric emission monitors are amongst the most sensitive of emission monitors, frequently used to monitor particulate densities at or near 0.01mg/m3, which is often considered to be the realm of mass balance instruments and scatter instruments. By contrast, it is difficult to keep opacity (and to a lesser extent scintillation) instruments clean enough to measure even 10mg/m3.

Particle Size

Particle size can affect the sensitivity of a Triboelectric Emission Monitor to create differences in sensitivity between different sites. Within most sites, however, there is usually a wide and reasonably constant distribution of particle sizes, so the effect is not seen. Particle size is believed to affect overal sensitivity in two ways: The available accumulated particle charge per unit mass (due to different energies, momenta, surface area, physical interactions) is higher for smaller particles, but the inherent sensitivity of the AC Triboelectric Emission Monitor is lower for smaller particles due to the masking effect of many small particles on each other. Because these two opposing effects cancel to some extent, Triboelectric Emission monitors are less sensitive to particle size, but the user should be aware that variations in sensitivity may still be observed. Scintillation and similar AC optical emission monitors are susceptible only to the latter effect; with no cancellation, they exhibit a much greater sensitivity to particle size.

The result is typically a linear relationship, valid over at least a 10:1 range. At higher levels, the response typically falls slightly under lab conditions, but rises slightly under filter output conditions, where bag leaks typically lead to both higher mass density and larger particles).

Particle Moisture

Moisture content (of the particulate) can affect both the material chemistry and material physics, and hence the sensitivity, particularly if the moisture is concentrated at the surface. The effect is decreasing sensitivity per unit mass as moisture increases, however this is partly offset by the increasing mass of the particulate, so for typical low-to-medium particle moisture, there is little observable effect.

Water Droplets

Water droplets in the gas will be detected as dust particles, but typically with 5 - 20 times lower sensitivity than dust. Water droplets are generally not a problem in the output from combustion processes, however for monitoring the output of wet scrubbers, the droplets may outweigh the dust by as much as 100 times, so the Emission Monitor should be mounted as far from the scrubber as possible, so that water droplets have evaporated, and the material surface has dried.

Humidity

Moisture in the gas (humidity) has not been shown to significantly affect the sensitivity of a Triboelectric Emission Monitor, as long as the conditions are stable. If the humidity is above 80% or unstable, water droplets may appear momentarily, and be detected, increasing errors.

Fallout

The accuracy of isokinetic testing and mass balance monitoring invariably suffers due to particulate fallout in the transfer ducting. However inline monitoring systems, including both AC and DC coupled triboelectric, do not suffer from this problem.

Maintenance

Because of their relative immunity to particulate buildup on the probe, AC triboelectric Emission Monitors are in most installations maintenance-free. By contrast, DC tribo and all optical devices require regular cleaning.

Cost

Triboelectric technology can be provided at a lower installed cost than any other particulate monitoring technology. Even though all technologies are in a continuous state of improvement and optimisation, this relationship will remain true.

Turbulence

Turbulence has no direct effect on sensitivity, however turbulent flow results in higher velocity, which increases sensitivity. In extreme cases, such as when a probe is positioned just after a bend on the inside, there may be sufficient local recirculating eddy currents that the Emission Monitor sees a particulate level which is both artificially high and remains long after the particulate flow has ceased. As with most gas stream sensing instruments, the installation recomendations should be observed to avoid these problems. Measurement locations should be chosen to avoid turbulence, regardless of the technology used.

Probe Size And Geometry

The recovered electrical signal from the probe depends on the effective coupling between the particles and the probe, and in particular the frontal surface area of the probe exposed to the flow. Varying the probe size and geometry is a convenient way to increase the sensitivity when the particulate is very insensitive and in low concentrations, or vice versa. The probe can vary from a few cm long stub to a conventional wire extending as far as 80% across the duct, to a welded mesh screen across most of the duct area (eg 5mm stainless steel wire in a 50mm or 100mm mesh). The most critical issue with large structures is the need for additional support, because the insulation at the supports may be degraded by high temperatures or surface pollution by product deposits. Both of these potential problems can be minimised by mounting the insulators out of the gas stream in, say, tubular ports through which cool clean air is allowed to bathe the insulators as it enters the stack.

Comparison Matrix

In the following table, a number of particulate emission monitoring technologies are compared in terms of sensitivity to the above parameters, and a number of other issues which, taken together form a reasonable basis for comparison of those technologies. The ratings attributed to competitive technologies are based on best objective estimates only, so readers are encouraged to create their own version of this comparison if more detailed, accurate or up-to-date information is available. Each rating is 1-9 (worst to best).

- 1= worst/unpredictable dependency,
- 5 = acceptable/dependency can be compensated
- 9 = best/ideal behaviour

Parameter Technology	AC-tribo (flowrate)	AC-tribo (density)	DC-tribo (density)	Opacity (density)	Scintillation (density)	Scatter (density)	Mass balance
Material	1	1	1	9	9	5	9
Velocity	9	5	5	9	9	9	7
NTP	9	5	5	5	5	5	5
O2	9	5	5	5	5	5	5
Sensitivity	9	9	7	1	4	9	9
Part. Size	7	7	7	1	1	3	9
Moisture	3	3	3	9	9	9	9
Droplets	5	5	5	1	1	1	1
Humidity	7	7	7	9	9	9	9
Fallout	9	9	9	9	9	9	1
Maintenance	9	9	5	1	1	1	1
Cost	9	8	7	3	6	3	1
Totals	86	73	66	62	68	68	66

Clearly the totals lack absolute credibility as they directly weigh all parameters equally, but they are included for completeness. In any case the final results are as expected:

- The narrow range of results suggests that most of these technologies have their place,
- Good overall scores were obtained by AC tribo (mass flow rate and mass density) and the more expensive scintillation and scatter technologies, and
- Traditional opacity, which will soon be superseded, scored worst.