# Continuous Monitoring of Particles after High Temperature Filtration

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**Abstract**
Electrodyanamic instruments have been used to continuously monitor particle concentrations after ceramic filters used in coal gasification, co-generation and high temperature metals and chemical processes. The technology is suitable for installation in processes operating at over 1000°C making it particularly suited for the long term measurement of the condition of the ceramic filter and indicating break down of filter elements. The early detection of failure of ceramic filters is important to avoid particulate carry through into downstream processes (which can cause substantial damage in turbines) and to stop the damage of filter elements close to the damaged filter.

The paper overviews the operation of Electrodynamic instruments and provides case studies from the operation in high temperature applications.

## Techniques for Continuous Particulate Monitoring

Technique and instruments used for continuous monitoring of industrial emissions must be robust and rugged to tolerate the conditions in the stack. However the need to operate at very high temperatures (up to 1000°C) after ceramic filters puts additional constraints on the selection of measurement instruments and the materials from which they are constructed. Electrodynamic instruments are capable of measuring at temperatures up to 1200°C, since the measurement technique is still valid at this temperature and it is practical to build in-situ instruments which can tolerate this temperature.

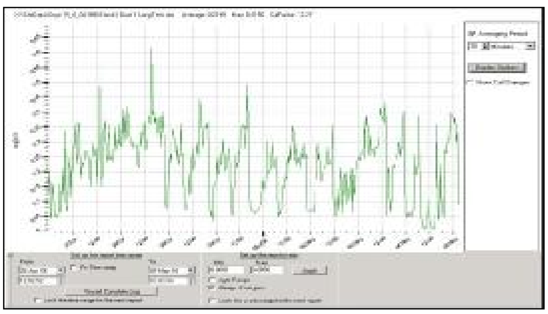

Figure 1: Particulate emissions from ceramic filter measured by Electrodynamic continuous monitor

Even though there are seven other core techniques used in commercially available particulate emission monitors [1] only few may be used to operate at very high temperatures due to the following limitations:

- Opacity - a cross stack optical method in which absorption of light is measured. Key limitation is difficulty of sourcing windows and lenses which can tolerate temperature.
- Dynamic Opacity (Scintillation) – a cross stack optical method in which the variation on absorbed light is measured. Key limitation at elevated temperature is interference from heat haze and sourcing of optical components.
- Back/Side Scatter – in which light reflected backwards from particles is measured. Key limitation is sourcing of optical components.
- Forward Scatter – an in-situ or extractive method in which light is directed at the particles and the light that is scattered (reflected) in a forward direction by the particles is measured. Key limitation at elevated temperature is cooling of gas in extractive systems and sourcing optical components for in –situ systems.
- Oscillating Filter (Vibrating tapered element) – in which the change in weight of a filter collecting particles is measured by measuring the change in resonant frequency of the support element. Key limitation at elevated temperature is that Vibrating element can not be sourced above 400°C.
- Beta Attenuation – an extractive method in which particles are collected on a filter and the absorption of Beta radioactivity is measured. Key limitation at elevated temperature is difficulty in cooling gases sufficiently before filter.
- Triboelectric: - a rod method in which the dc current caused by particles colliding with a rod is measured. Key limitation at elevated temperature is cathodic interference current from heated rod.

## Electrodynamic Technique

Principle of Operation:
In an Electrodynamic system, a grounded metallic sensing probe is installed across part of the stack of

interest and this rod is connected to signal processing electronics capable of amplifying and measuring an AC current of RMS magnitude in the order of 10pA. Particles in the stack to be monitored carry charge as a result of upstream activity and these particles induce an AC signal as they pass the rod. The magnitude of the AC signal is a function of the average charge per particle and the variation in the spatial distribution of the particles. This AC signal is proportional to total mass concentration in conditions where the charge per particle remains constant (a function of particle type, particle and size and the process conditions) and stack conditions where the particle number concentration is small (since the particle distribution follows a Gaussian distribution in steady flow conditions). The proportional relationship between particle concentration and instrument response has been validated in regulatory approvals in Germany by TUV and UK by MCERTS [2]. Since the AC signal is primarily derived from charge induction from particles passing the rod (unlike Triboelectric instruments which measure the direct current caused by particles colliding with the rod), the related problems of rod contamination and velocity dependence are minimised.

Emperical tests have shown that the Electrodynamic signal is inversely proportional to particle size [2]. This is consistent with the theory that the signal is proportional to the total surface area of the particles which effects the total charge per particle.

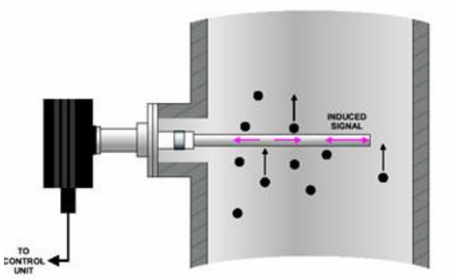

Figure 2: Schematic of charge induction in Electrodynamic sensor caused by charged particles passing the rod

In many industrial processes especially those controlled by ceramic and fabric filters where the filter element surface acts to pre-condition the particle charge, the charge per particle in the final emission stack is sufficiently constant to permit a reliable calibration in $mg/m^3$ by comparison to the results of an isokinetic sample (gravimetric sample under matched velocity conditions). The technique is best used in processes with constant particle types.

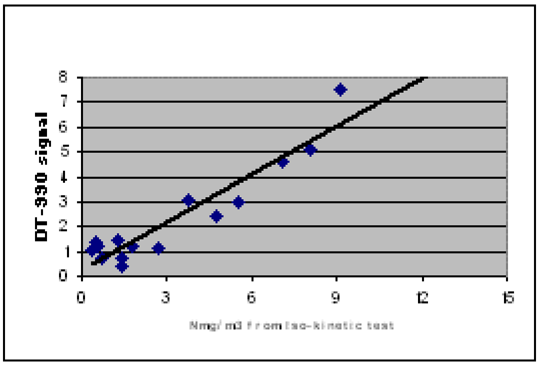

Figure 3: Calibration of DT990 Electrodynamic instrument with isokinetic test

Practical Considerations for high temperature applications:

- The sensor rod can be made of an FeCrAl alloy which can tolerate temperatures of up to 1200°C.
- Analysis of the frequency components of the AC signal is used in certain instruments to improve accuracy.
- The sensor rod can tolerate contamination without reduction in performance since the measurement signal derives from induction rather than collision.

Use and limitations of Technology:

Electrodynamic instruments are used to satisfy qualitative and measurement requirements on Bagfilters and ceramic filters in the metals, mineral and chemical industries. Their adoption in UK is extensive and their use in Europe, Japan and Australia is widespread. Regulatory approvals exist for instruments in the UK and Germany according to MCERTS and TUV (BImSchV 17) respectively. Technical limitations are as follows:

- The use of Electrodynamic technology for particulate measurement requires applications with predictable particle type and pre-charge, non-condensing conditions and a minimum velocity of 5m/s. There are only minor effects of changing velocity if the velocity is greater than 8m/s
- The instrument cannot be used for measurement with the presence of water droplets, however this is rarely an issue in high temperature applications. The

instrument can discriminate between solid particles and water vapour.

- The technology has limitations in applications in which the pre-charge on the particle is likely to change. In practice this covers Electrostatic Precipitator (EP) where charge on the particle may be changed by EP condition, processes where the particle type may change and pre-arrestment locations in combustion applications in which flame conditions vary significantly (since this effects ionisation which changes charge on the particles). However in practice most industrial applications are more constant rather than batch laboratory processes and therefore this limitation is in practice relatively small.
- The process limits for the technique are that it measures all particles from 0.1micron and larger (response is inversely proportional to particle size), measures particle concentration from below 0.1mg/m$^3$ to over 1000mg/m$^3$ and should be used in applications where there is a minimum velocity of 3m/s.

Construction of Electrodynamic instruments

An Electrodynamic instrument comprises of a sensor which is mounted in the stack via a coupling or flange connection. The version of the sensor used at temperatures to 1200°C includes a ceramic insulation (to isolate the rod from the stack wall), a FeCrAl sensor rod and a heat shield to protect the sensor electronics from the stack temperature. Other variants of the sensor are available for operation up to 250°C, 400°C and 800°C.

Figure 4 High temperature Electodynamic particulate sensor capable of monitoring in stack temperatures to 1200°C

The sensor is connected to a control unit via a single cable which provides all sensor power and communication with the sensor. In versions using modbus for commumication the cable length can be up to 2000m in length. The control unit is used for all user interface, instrument set up and provides 4-20mA, RS232/485 and Ethernet outputs for connection to external plant control systems, PLCs and Plant LANs.


Figure 5 Control unit used for user interface plant outputs and sensor configuration.

## Monitoring the Efficiency of High Temperature Filtration

Types of applications

Filtration systems are used in a growing number of high temperature applications in coal gasification, co-generation, incineration and high temperature metals and chemical processes. Ceramic filters are able to operate at temperatures in excess of 600°C and provide high levels of particulate removal in these applications. The continuous monitoring of the efficiency of the filtration system can be important for a number of reasons:

Plant protection

- To provide information that particle levels have increased so that the plant can be shut down before damaging expensive downstream equipment (eg turbines in coal gasification plant) High temperature filters are often fitted before further process plant used to remove energy from the high temperature gas and therefore protecting this plant from damage is of real relevance.
- In coal gasification processes high pressure and high temperature syngas is cleaned by a ceramic filter before passing into the turbine for electricity generation. The condition of the filter is critical to ensure particles do not pass into the turbine causing damage to the turbine blades and casing.
- Electrodynamic sensors have been successfully using for turbine protection on coal gasification pilot plant.

Environmental legislation

- To provide data to satisfy environmental legislation to prove that the plant is operating below defined emission limits (for example an emission limit of $10 mg/m^3$ is now required for all new incineration plant in Europe and continuous monitoring is required to prove plant compliance)

Figure 6 Electrodynamic sensor fitted in incineration process after ceramic filter

- The chemical, metals and mineral industries are increasingly fitting continuous monitors to satisfy environmental legislation and meet ISO-9001 commitments. For example the carbon black industry uses Electrodynamic sensors to monitor emissions for two reasons. First due to the high temperature of the flue gas from the carbon black manufacturing process (furnace process) and secondly due to the resilience of the sensor to any contamination caused by carbon.

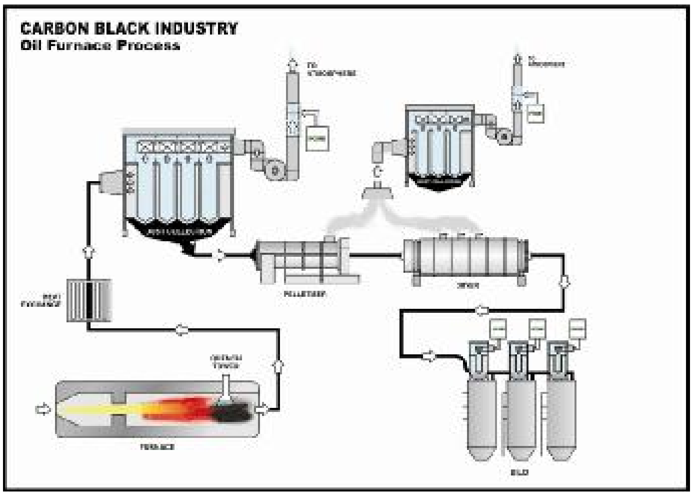


Figure 7 Emission points for high temperature particulate monitors in the carbon black industry

Reduced filter running costs

- To minimise the damage which occurs when a ceramic filter fails, by stopping the plant before consequential damage to other filter elements in the vicinity of the failed filter. This helps reduce downsteam particle carryover and reduces the cost of replacing failed filter elements which can be considerable.
- To assist maintenance personnel locate the leaking element in a large filter system. This is done by synchronising the output from the particulate monitor to the cleaning sequence of the filter and using the dynamics of the dust signal to pin point which row of elements when cleaned is causing high dust levels and hence is beginning to fail.

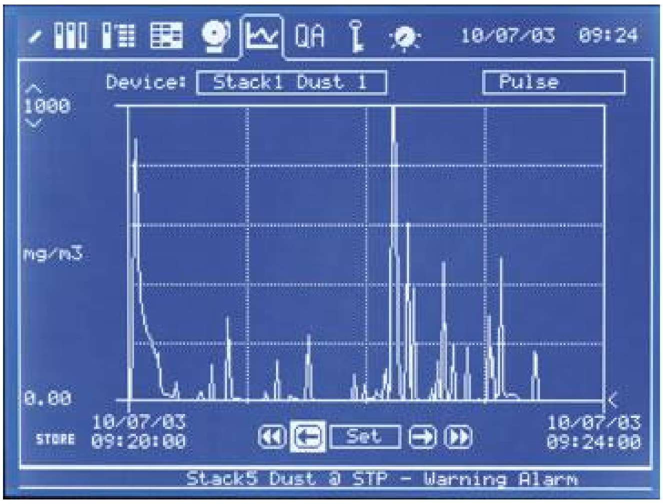


Figure 8: Trends of particulate levels synchronised to cleaning controller permit location of failed filter element to be located

- Plant operators use the graphics screens on Electrodynamic instruments to view emissions trends and hence diagnose filter condition.

Industrial experience

Electrodynamic instruments have been used in a growing number of high temperature applications for monitoring the levels of particulate after ceramic filters. These include incinerators in UK, France and China, Coal gasification projects in UK and US, emissions monitoring in sinter plant steel applications in Australia, South Africa, Sweden and the UK and high temperature calcining processes in UK and

Argentina. In addition and of relevance to this conference in Osaka, Electrodyamic instruments are already being used for high temperature applications in Japan including those on incinerator and chemical processes built by Hitachi Shipbuilding, Mitsubishi Heavy Industries and Mitsubishi Chemical [3].

**Summary**

Electrodynamic particle emission monitors can be constructed to work in industrial applications with temperatures of up to 1200°C and have been used in high temperature applications in incineration, coal gasification and the metals industry using high temperature filtration including ceramic filters. The technique requires no optics or active sensor components which limit the use of opacity and light scatter particle measurement techniques in high temperature applications.

The technique measures the ac current induced in a sensor rod inserted across the emission stack and in spite of cross sensitivities to particle size, particle material and particle charge can be calibrated in $mg/m^3$ by reference to an isokinetic sample in many industrial processes with emission control equipment where these conditions remain sufficiently constant

Practical instruments using this technique are being used in high temperature industrial applications in UK, Germany and Japan. These instruments are sufficiently accurate to meet regulatory approvals in UK (MCERTS) and Germany (TUV) for continuous emission measurement.

## Conclusions

High temperature Electrodynamic particle emission instruments (designed to operate at 800°C) are suitable for the long term continuous monitoring of emissions from industrial processes and monitoring the condition of ceramic filters. Since the early detection of filter failure is critical to reduce damage and minimise down time in a ceramic filter, these instruments can assist reduce filter running costs as well as reduce emissions. These instruments have sufficient accuracy and reliability to meet the emerging need for high temperature particle emission measurement practically and cost effectively. In the future, the proportion of Electrodynamic instruments used at even higher temperatures (to 1200°C) is forecasted to increase in line with the growth of high temperature filters in industrial processes.

## REFERENCES

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