Optimising the efficiency of dust control equipment with a novel forward–scatter particulate monitoring instrument

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ABSTRACT

This paper describes the principle and operation of a novel near-incident forward scatter particulate monitoring instrument, designed not to be affected by changing particle size after dust arrestment plant. The paper describes the process control benefits of using this type of instrument after bag filter; electrostatic precipitator and cyclone type particulate control processes and also discusses its use to satisfy new European Legislation.

Environmental regulations and responsibilities are stimulating Industrial Process Operators to minimise particulate emissions from Fabric Filter and Electrostatic Precipitator Dust arrestment plant by optimised maintenance and operation programmes. The on–line monitoring of particulate emissions plays a fundamental role in this optimisation providing the evidence and feedback of any improvements. The new instrument overcomes the limitations of many existing instruments, since its calibration (and hence accuracy) is unaffected by changing particle size as the arrestment plant becomes more efficient.

Keywords: Emission, Monitoring, Particle Size, Cross-Sensitivity.

1) Existing Practise For Continuous Particle Emission Monitoring From Industrial Control Equipment

1.1) Industrial Dust Control Equipment

Particulate emissions from industrial plant are generally controlled by one of three major control technologies:

1) Fabric Filter dust collectors in which the particles are collected on a filter membrane. These devices are also referred to as Baghouses and Bag filters.
2) Cyclones in which the particles are collected by centrifuge.
3) Electrostatic Precipitators (ESP) in which particles are electrostatically attracted to a High Voltage plate.

Fabric filter dust collectors have played an increasing role in the industrial market during the past 20 years due to their ability to meet falling emission limits. They have the capability to reduce emissions even below 1mg/m^3 the emission limit for toxic particles (e.g. lead from battery factories). Cyclones are used less frequently these days as a final control device since they are only efficient with larger particles (i.e. woodchips). Electrostatic Precipitators are still used to control emissions with high volumes of flue gas (e.g. Cement Kilns and Power Plant), although new plant might choose Fabric Filters due to their higher efficiency. ESPs are also used with wet collectors when gaseous emissions must also be reduced.

1.2) Reasons For Continuous Monitoring

Regulators and process operators continuously monitor the emissions from these types of particulate arrestment plant for two reasons: First to ensure emissions are below legal limits and secondly and more fundamentally to ensure the proper operation of the arrestment plant, since if the arrestment plant is working correctly and it is fit for purpose, no emission limit will be exceeded.

It is therefore common practice to monitor emissions continuously and the data is recorded and analysed to assist regulatory compliance and arrestment plant control.

1.3) Particle Size Sensitivity Limitations Of Continuous Monitoring Technologies

There is a range of proven technologies for continuously monitoring particulate emissions from industrial processes and the appropriateness of each is dependent on the specific application. The core technologies are:

- Opacity: In which the amount of light absorbed by particles in the path of a cross stack light beam is measured.
- Scintillation: In which the amount of flicker caused by particles crossing a cross stack light beam is measured.
- Light scatter: In which the amount of light scattered (reflected) by the particles from a

light beam passing into the stack is measured.

- Electrodynamic: In which the variation in electrical signal induced by particles that are naturally charged passing a sensor rod in the stack is measured.
- Triboelectric: In which the amount of current produced by particles colliding with a sensor rod in the stack is measured.

The parameter measured by the instrument can be related to particle concentration, and therefore instruments can in many circumstances be calibrated in absolute terms (mg/m^3) by comparison to the results of an Isokinetic test. It can therefore be understood that the instrument is not actually measuring dust concentration rather inferring it from the measurement of a parameter that can be correlated to dust concentration, (E.g. light absorbency, electrical signal). This leads to the "Achilles heal" of all continuous particulate monitors in that the measured parameter may also be affected by other changes in process and particle characteristics. The cross sensitivities are specific to measurement technique, however all in situ-techniques are sensitive to both the type of particle and the size of the particle.

In most industrial applications (with the exception of incineration) cross sensitivity to particle type is not a problem, since the application is fixed and therefore the type of particle remains relatively constant (e.g. Lime Stone dust comes from a kaolin plant). However the issue of particle size sensitivity is of far higher significance. Emissions from industrial plant increase when dust collection equipment becomes less efficient or fail. In these circumstances both dust concentration and particle size change together, meaning the accuracy of the measured dust concentration at the time one might be most interested in its validity, is often in error due to particle size cross sensitivities.

2) Near Incident Forward Light Scattering (Pro-Scattering)

2.1) Principle Of Operation

A new 'near–incident' forward scatter particle emission instrument has recently been developed to overcome the cross-sensitivity to particle size discussed above. The theory behind light scattering is well understood in that the total amount of scattered light from a particle cloud is dependent on the angle between the incident beam and the measured scattered angle. (Reference: Jones)

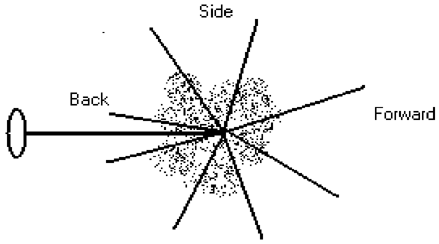

Figure 1: Types of light scattering

The scattered light between 90 and 180° (referred to as back-scatter) is sensitive to particle refractive index and particle size and shape while the scattered light less than 90 is less dependent on particle type. As the scattering angle is reduced towards 0 (i.e. small angle with incidence beam) the cross sensitivity to particle size also diminishes significantly.

The instrument has been designed with a scattering angle of between 5 and 10° hence significantly reducing the effect of changing particle size. This results in added complications in practical implementation, but provides the key characteristic of reduced particle size insensitivity.

2.2) Practical Implementation

A probe-based design has been used to minimise errors in measurement arising from alignment. A probe permits the incident beam angle and scattered light signal to be maintained at a defined angle with a high level of precision. Changes in this angle which would be likely in a cross stack design due to stack wall movement are eliminated by the use of rigid materials and mechanics.

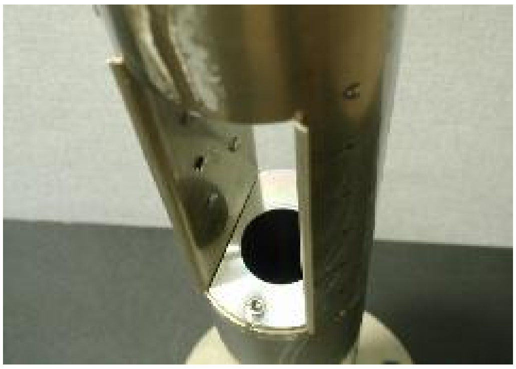

Figure 2: Photographs showing measurement volume of Near Incident Forward Scatter Instrument

It is desirable to have as large a measurement volume as possible as well as use a small scattering angle and therefore it was decided to use a design where all the concentric scattered light in a particular range is used by putting the axis of the receiver lens on the same axis as the incident beam. This introduces the added challenge of blocking the incident beam from being monitored by the detector since the incident beam is several orders of magnitude greater than the scattered signal. This is accomplished by a periscope that deflects the incident beam after scattering and careful beam dumps.

To ensure the instrument is rugged enough to operate continuously in an aggressive stack environment all optical surfaces are recessed well away from the stack gases and air purges are used to provide positive displacement away from these surfaces.

The instrument must be usable at elevated stack temperatures (up to 400°c) so all electronic components must be near the stack wall to ensure adequate cooling. This required a design in which the diode laser beam is reflected towards the measurement chamber and receiver by a retro reflector at the far end of the tube. Optical fibres were not practical due to light coupling efficiencies.

It was an operational and regulatory requirement to be able to automatically measure and compensate for errors caused by contamination and any instrument drift. A zero and span was therefore incorporated.

1.3) Operating Characteristics

The developed instrument is proving itself to be suited for operation in a stack environment. It key performance criteria are:

Dust Concentration range	0.1 to 100mg/m³
Max Temp:	0- 400°C (optional)
Length of measurement cell	300mm
Probe length into stack	800mm

The sensor connects directly to a control unit that provides user interface, data display, plant outputs and recording.

Of key importance to bag filter and other dust arrestment plant activities is the instruments response to particle size. The instrument is proving to have a relatively unchanged response to particle size in the range 0.3 um to 5um the typical particle size found after bag filters. At larger particle sizes the response still shows a cross sensitivity to particle size.

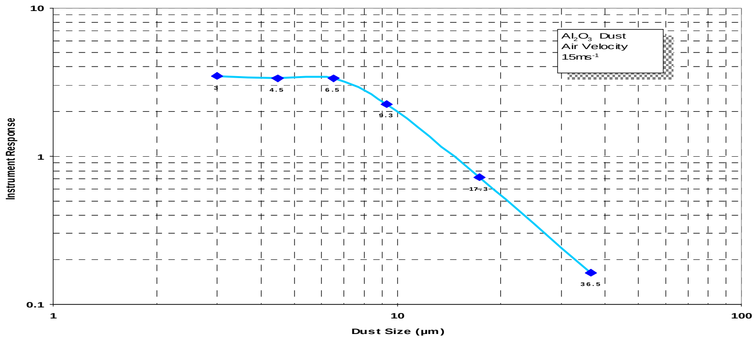

Figure 3: Response to particle size (near-incident forward scatter)

These results compare very favourably with the particle size response of a forward scattering instrument using a larger scatter angle of 15°. This instrument has a peak in response for particles of approx 1um (the wavelength of light used) and then a drop off in response with increasing particle size. It is this response that makes the calibration unreliable in bag filter applications since the particle size increases at the time of filter failure.

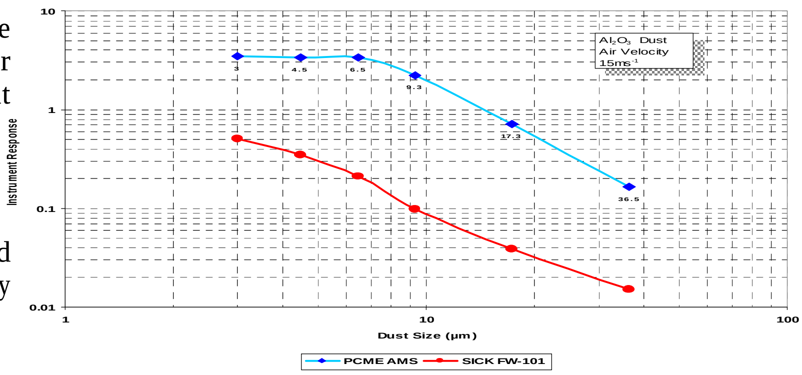

Figure 4: Comparison of response to particle size (15° forward scatter and near incident forward scatter)

An additional benefit of the near forward particle size technique is that response to different particle types is relatively unchanged, making it suitable for incinerator applications where the type of dust can be dependent on different fuel sources from one day to another.

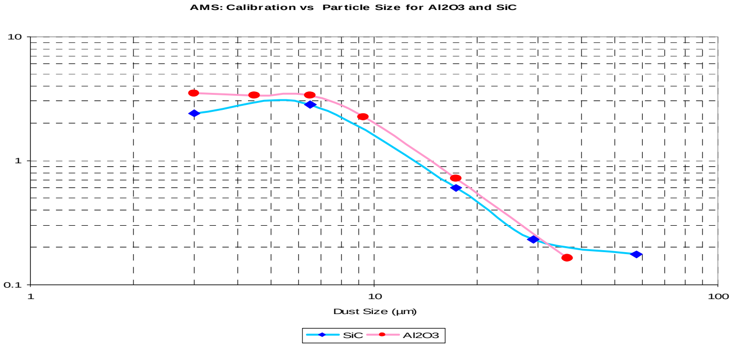

Figure 5: Comparison of response to SiC and AL2O3 (near-incident forward scatter)

3) Operational Benefits Of Using Particle Size Insensitive Instrument

3.1) Accuracy And Emission Reduction Benefits In Bagfilter Application:

Bag filters comprise a number of long tube filter bags hanging in rows from a clean air manifold. Air passes from the dirty side of the process, through the filter tube (which is given its cylindrical shape via a metal cage) up the inside of the tube to the clean air manifold and then on via a fan to the emission duct or stack

Dust removal occurs as the dirty air passes through the filter bag. The particles that pass through the filter in the initial stages are those that are smaller than the 'pore-size' of the filter media. However as the filter becomes loaded with particulate the 'effective' pore size reduced since gaps on the filter media are filled by particulate that plug the pores. Therefore the filter becomes more efficient and the size of particles passing through the filter reduces. In high filtration applications the bags are often pre- coated with limestone to ensure adequate particle entrapment.

Periodically the filter is cleaned to remove caking particulate from the filter media since otherwise the pressure drop across the filter would increase too much and the filter would be damaged. Therefore the emissions from a bag filter are dynamic with the dust loading and particle size changing depending on the stage of cleaning. In a periodically cleaned pulse jet collector this variation is regular and predictable.

Particulate is abrasive and therefore filters fail for one of two main causes:

- Rupture of a bag filter: In which case the increased particles passing through the hole have the increased size of the particles entering into the process. The particle size distribution of the emission is bimodal, made up of both the filtered and input particle size distribution.
- Wear of the filter media (especially seen with abrasive dusts such as in cement processes) in which the filter pore size gradually becomes larger and hence the total particle size range increases

The benefits of using an instrument to monitor particle emissions that is not particle size sensitive is to eliminate the errors in measurement which arise from particle size dependence. These errors can be significant under start up and failure conditions and to date have limited the benefits of continuous particle emission monitoring as follows:

i. After rebagging on start up:

After a bag filter is rebagged, emissions will fall for some time as the bags becomes coated and the bags become more efficient. The particle size slowly reduces. An instrument that is particle size dependent shows an increase in signal (due to enhanced response to smaller particle sizes), which is interpreted as an increase in dust even though, the emissions have fallen.

Implications are:

- The option to reduce emissions by fine-tuning the bag filter by further coating the bags or changing the cleaning timing on the bag filter is not possible since there is no effective feedback on the gains.
- Any calibration done when the bag filter is first done is not valid. The instrument will over-report emissions if particle sizes remain reduced by the bag filter. This can cause significant reporting and operational problems to a process operator with an emission limit with no ceiling above normal emissions.

ii. Filter failure:

As the particle concentration and particle size increase the instrument may not detect an increase in signal due to reduced sensitivity to the dust. The implications of this are that

- This will lead to gross underreporting of emissions at the time of filter failure, making the instrument of limited use. From a plant prospective there maybe increased environmental liability as a result of this false sense of under-reported emissions.
- The calibration vs. dust concentration is non–linear making interpolation beyond emission levels experienced during calibration of limited use. Recent regulations disallow interpolation for instruments that are particle size dependant.

Hence the benefits to a plant operator from the increased accuracy resulting from independence to particle size are:

- Increased potential to reduce emissions by fine tuning arrestment plant
- Reduced liability by elimination of reporting errors on filter failure
- Linear calibration curve, which can be interpolated to emission limits saving time in creating different operating conditions during calibration.
- Accurate reporting of concentration (and derived mass emissions for emissions trading).

Many of these benefits are provided by the near incident light scatter instrument.

3.2) Benefits In Electrostatic Precipitators

The benefits of insensitivity to particle size for particle emission monitors is not restricted to bag filter application. Similar arguments are also relevant to ESP control equipment where the particle size can change depending on the voltage to the ESP plates and the migration velocity through the ESP. In addition during soot blowing there can be significantly increased particle size.

3.3) Meeting New Regulations

Operators of municipal waste incinerators, large combustion plant and cement kilns falling under the municipal waste directive will also find a real benefit of using particle Automatic Monitoring Systems (AMS) with reduced sensitivity to particle size. These industrial processes will soon be forced to use new CEN standards for emissions monitoring which place a large incentive on a stable and reliable calibration.

Under CEN-13284-2 (currently in draft status), operators will be required to calibrate an instrument over 3 days taking 15 reference samples (by iso-kinetic sampling). Typical calibration costs of 5,000 euro to 10,000 euro are not unexpected. However the standard also requires that if the particulate loading increases 10% over the maximum level experienced during initial calibration then the calibration must be extended to include this new level. This has significant additional cost implications. However if the initial calibration can be extended by increasing the plant emission output by adjusting the dust collection equipment this becomes less necessary. This type of extended calibration is only possible with instruments that are not sensitive to particle size since otherwise a false calibration would arise.

With the increased legalistic use of the results from continuous particle instruments the stability of calibration will be a feature of increased importance.

Reference

A. R. JONES (1999), Light Scattering for Particle Characterisation, Progress in Energy and Combustion Science 25 (1999), pp 1-53