STATIONARY SOURCE EMISSIONS

EMISSION MONITORING AND MEASUREMENT OF FLUE GAS FLOW RATE

EN ISO 16911 'Stationary Source Emissions – Manual and automatic determination of velocity and volume flow rate in ducts.

Operators of combustion plant need to know the flue gas flow rate in order to calculate the mass release of pollutant emissions. The flue gas flow rate (m3/s) is multiplied by the concentration (mg/m3) of pollutant, e.g., NOx, to give the mass release rate in mg/s. This information may be required for emissions trading, compliance or inventory reporting, or for air quality modelling purposes.

The standard on flue gas flow rate measurement was published in 2013: EN ISO 16911 'Stationary Source Emissions – Manual and automatic determination of velocity and volume flow rate in ducts. The scope of the standard, based on the original mandate from the European Union, is linked to the requirements of European Directives, including the Industrial Emissions Directive (IED) and the EU Emissions Trading System (EU ETS) which allow this alternative 'measurement' approach for CO2 and requires it for emissions of N2O and CH4 from other sectors, all subject to defined uncertainty requirements. European Directives require the use of CEN standards when available.

The standard is divided into two parts. Part 1 defines manual Standard Reference Methods (SRM) to be used for the calibration of continuous stack flow monitors and for other compliance purposes, such as periodic testing. Part 2 of the standard applies to continuous monitoring and specifies the requirements for the certification, calibration and ongoing control of continuous flow monitors.

Part 1: Manual reference method

Part 1 of the standard is performance based, that is, a number of different techniques may be used as the manual reference method provided that the specified performance requirements are satisfied. The alternative techniques include: velocity traverses with Pitot probes (various designs) or vane anemometers; tracer (dilution) and tracer (time-of-flight) methods. Under certain circumstances, flow calculation from fuel consumption can be used to perform compliance checks and a mandatory calculation approach is also provided in Part 1 (Annex E).

Table 1 summarises the applicability of the different techniques.

Measurement Objective	Applicable Techniques
Velocity profile	Point velocity measurement: - Pitot tubes (ΔP measurement) - Vane anemometer
Swirl angle	Point swirl angle measurement: - S-type Pitot tubes - 3D or 2D Pitot tubes
Periodic measurement of average velocity (flow rate)	- Pitot tube traverse (ΔP) (averaged) - Vane anemometer traverse (averaged) - Tracer dilution technique - Tracer transit time technique - Calculation from fuel consumption
Calibration of flow monitors for average velocity (flow rate)	- Pitot tube traverse (ΔP) (averaged) - Vane anemometer traverse (averaged) - Tracer dilution technique - Tracer transit time technique - Calculation from fuel consumption

Table 1: Applicability of manual reference techniques

Point velocity measurements are, evidently, required when measuring the velocity profile in order to determine if a given measurement plane is suitable for the installation of a flow monitor, for example. Any type of Pitot tube or vane anemometer with a traceable calibration can be used for this purpose, provided that the level of swirl is low (nominally less than 15° swirl angle at all traverse points). If the level of swirl is significant, then the traverse must be conducted using a 3D or 2D Pitot, noting that a conventional S-type Pitot can be operated as a 2D Pitot with measurement of the swirl angle. The 3D approach, as the name suggests, measures all three velocity components, including the axial velocity that is required for an unbiased flow rate determination.

The spherical (5-hole) Pitot, shown in Figure 1a, is an example of a 3D device. This is inserted into the flow and turned until one of the ΔP measurements is nulled. Wind tunnel calibration relationships are then used to calculate all three velocity components from the various measured ΔPs. The operation of 3D Pitots is described in detail in US EPA Method 2F.

Figure 1a: Spherical (5-hole) Pitot head

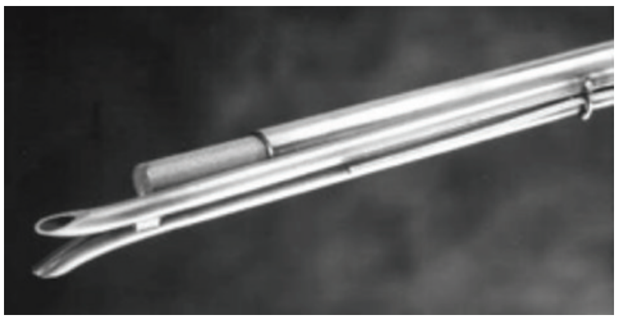

Figure 1b: S type Pitot head

The S-type Pitot, shown in Figure 1b, is commonly used to establish iso-kinetic sampling conditions when measuring dust concentrations. This is normally inserted into the flow so that the 'impact' orifice faces into the flow and the 'wake' orifice is then positioned at 180° to this. Operation as a 2D Pitot is described in detail in US EPA Method 2G. Note that, if a Pitot tube is used in a configuration with a closely coupled gas-sampling probe, then the device must be calibrated in this configuration.

For determining the average velocity, the traverse points are located at centres of equal area so that a simple average of the point readings gives an area weighted average in a duct of circular cross-section. The procedures for determining the required number and location of points are specified in EN15259, noting that the 'tangential method' is required by EN ISO 16911, i.e., the centre-line of the duct cannot be included. Twenty measurement points are normally sufficient in large ducts.

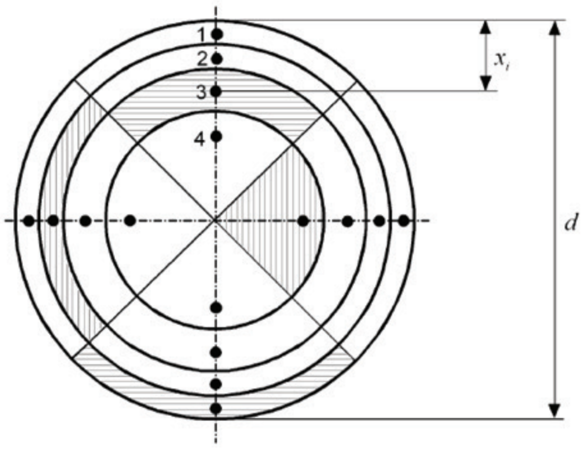

Figure 2 EN15259 Traverse Points

The field trial validation indicated that lack of uniformity of the flow profile (Figure 3) caused by a poor measurement location did not significantly affect the average velocity determination. That is, a 20 point average from a poor flow profile gave the same result as a 20 point average from a uniform flow profile.

Performance requirements and quality assurance requirements are specified for each technique. For Pitot tubes, a pre-test leak check is required and, when using an electronic pressure reading device, a daily calibration check is required using a liquid manometer device (temperature corrected) or a calibrated pressure sensor with an uncertainty better than the test device. The repeatability also needs to be determined at a single measurement point (the standard deviation of five consecutive one minute velocity readings). Each point velocity measurement must be obtained from a one minute average ∆P based on a continuous measurement or at least three separate readings.

A velocity traverse to EN 15259 does not have sufficient resolution to capture the very low velocity boundary layer at the duct wall. For a large duct, this can optionally be measured according to US EPA Method 2H. However, the correction is usually very small and it is normally sufficient to multiply the measured average velocity by a Wall Adjustment Factor of 0.995 for a smooth duct or 0.99 for a rough (brick-lined) duct of circular cross-section. This is a requirement when calibrating a flow monitor.

Tracer transit time methods determine the bulk (average) velocity directly by recording the time taken for a tracer material to travel between two measurements stations (∆t). The distance between these two stations, situated in duct work of constant cross section, is divided by the measured time-of-flight to obtain the average velocity. The example in the standard is based on the injection of a radioactive tracer, upstream of the flue. Two sets of clamp-on detectors are then used to detect the arrival of the tracer at two different heights within the flue. The medians of the recorded tracer concentration peaks are extracted so that the shape of the detector response is taken into account to obtain an accurate ∆t.

In order to obtain the volumetric flow rate the average velocity must be multiplied by the duct's cross-sectional area. EN ISO 16911 requires the Test Laboratory to measure the duct dimensions, across at least two axes, rather than simply relying on plant drawings.

The tracer dilution method directly determines the flue gas flow rate and does not, therefore, require the cross-sectional area to be known. A tracer is injected into the flue gas, for a short period of time, well upstream of the flue, so that the tracer is intimately mixed with the flue gas. The concentration of tracer in the flue gas is then measured. A one-off EN 15259 concentration traverse must be performed to demonstrate that the tracer is well mixed for the given injection configuration. Simple dilution relationships are then used to calculate the flue gas flow rate from the tracer injection flow rate and concentration.

If all of the above techniques are regarded as different implementations of the same method, the ensemble average uncertainty, based on validation field trials, is estimated to be ± 5% at 95% confidence, assuming that the flow is non-swirling. However, it is anticipated that a lower uncertainty can be obtained using a specific technique in a given application. The Test Laboratory must calculate the uncertainty of the method, using the approaches described in the standard, and ensure that this complies with the requirements of the Test Objective.

Part 2: Automated measuring systems

Part 2 of the standard is also performance based, that is, provided that the specified performance requirements are satisfied, any continuous monitoring technique can be employed, e.g., single point or averaging Pitot tubes, hot wire or hot film sensors, point or cross-duct ultrasonic devices (Figure 4) or correlation (pattern matching) devices. However, it is recognised that the uniformity of the velocity profile at the monitoring location, and the stability of this profile with regard to plant operations, may affect the choice of flow monitor and how this is configured.

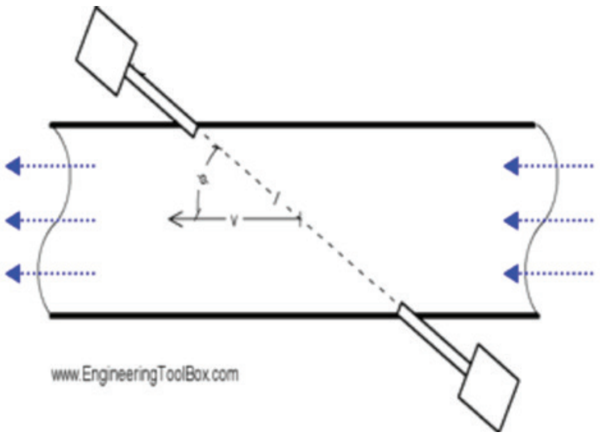

Figure 4: Cross-duct ultra-sonic flow meter configuration

The standard, therefore, encourages a pre-investigation of the velocity profiles at the proposed monitoring location, based on point velocity measurements (see Part 1). For a new plant, this can be conducted using Computational Fluid Dynamics. The survey needs to be performed at the normal base load operating condition and the minimum stable operating condition.

Table 2 presents informative guidance to assist in the selection of a flow monitor. The profile is assessed by means of three parameters:

- Reproducibility - the deviation in the normalised velocity profile shape between the minimum and maximum plant flow rates
- Crest factor - the ratio of the maximum to average velocity
- Skewness - the ratio of the average velocities either side of the duct centre-line

If a pre-investigation (velocity survey) is performed, the plant does not then have to operate at minimum load when the monitor is calibrated.

The Quality Assurance (QA) approach defined in the standard is based on EN 14181 which defines three Quality Assurance Levels (QALs). QAL1 requires that the instrument is fit for purpose and this is satisfied by an appropriate instrument certification. QAL2 requires in-situ calibration of the CEM using parallel test data obtained by an accredited Test Laboratory using Standard Reference Methods (SRMs) defined in Part 1. The calibration must also be checked annually by the Test Laboratory by means of an Annual Surveillance Test (AST). QAL3 requires the ongoing monitoring of instrument zero and span drift.

QAL1 defines additional certification requirements and emphasises the need to have an appropriate reference material, or surrogate approach, for checking the zero (or low level) and span (high level) instrument capability. For example, a Pitot tube would require the capability to check the ΔP measurement combined with procedures to ensure that the pressure tappings remain blockage free. The instrument configuration, and sensitivity to changes in flue gas conditions and velocity profile shape, must also be audited by the Test Laboratory during the certification field trial.

QAL2 defines the approach to be taken for in-situ calibration of the flow monitor. EN14181 employs Emission Limit Value (ELV) and an uncertainty level specified in the relevant European Directive when assessing the quality of the calibration. Since these parameters are not defined for flue gas flow rate, surrogate values are defined in the standard for the ELV (120% of the maximum measured value) and the uncertainty (Δσ = 4%). Testing does not have to meet any particular time constraints, e.g., a QAL2 can potentially be conducted in one day, and the number and range of the measurement points can be reduced if a pre-investigation of the flow profile is conducted, as noted above. In addition to the usual variability (QAL2) and bias (AST) assessments, the quality of the linear regression between the test results and continuous monitoring results must be good (R2 > 0.9).

Calculation of the flue gas flow rate from fuel consumption can be also employed for continuous monitoring purposes (according to Part 1 Annex E) subject to QAL2/AST verification.

QAL3 requires the usual control chart approach for the assessment of instrument drift using the internal reference points established under the QAL1 certification.

Concluding remarks

Applying this standard to existing combustion plant poses a number of challenges relating to a) sample port provision and access, b) choice of manual test method and c) implementation of the QA requirements in a consistent and meaningful way.

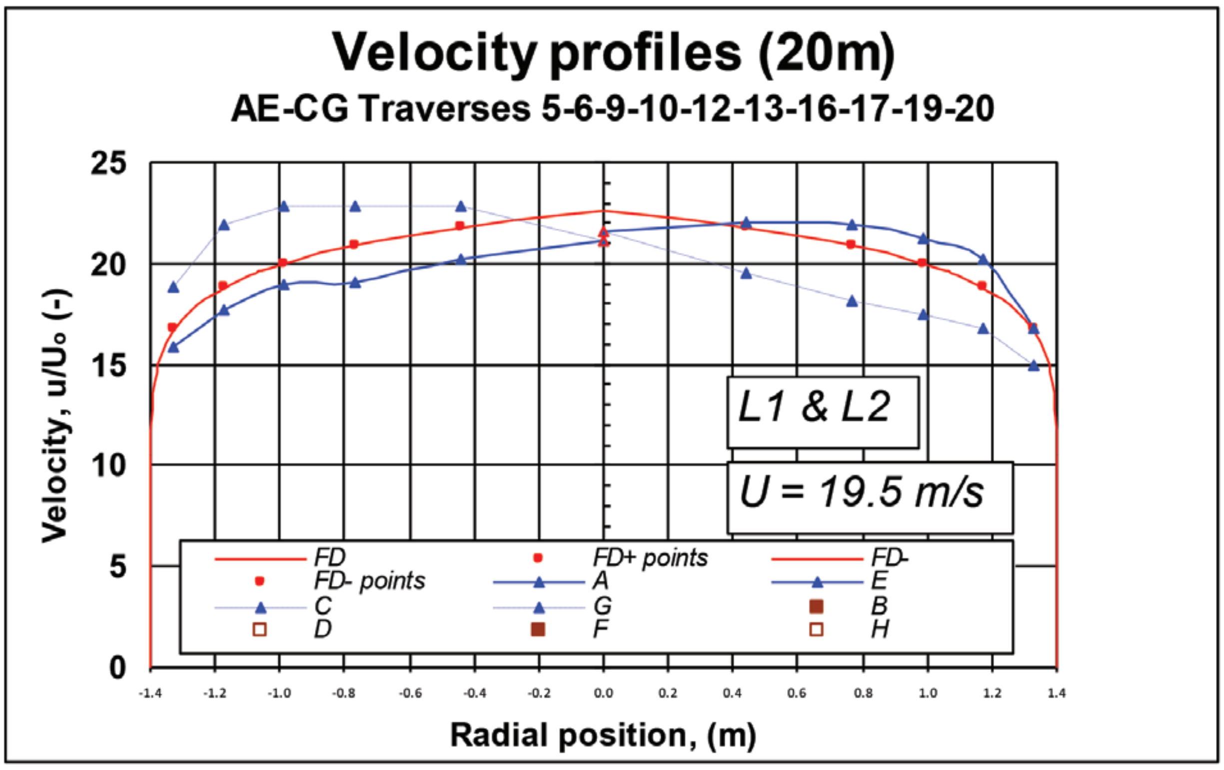

Figure 3: Velocity profiles from a validation field trial

Table 2: Informative guidance on monitoring arrangements

Reproducibility of normalised profile	Crest factor	Skewness	Monitoring approach	Comments
< 5%	< 1.3	< 1.2	Single probe point measurement (or limited path length)	Flow profile unlikely to change
> 5%	< 1.3	< 1.2	One cross-duct monitoring path	Flow profile is expected to change with flow rate
	> 1.3	< 1.2	One cross-duct monitoring path in the plane with the highest skewness	Flow profile is expected to change considerably with flow rate
	> 1.3	> 1.2	Two cross-duct monitoring paths	A skewed flow profile, possibly due to swirl, i.e., the point in the profile with the maximum flow rate is rotating and the best way to secure a representative average is to monitor in a cross or across two chords

However, the standard provides a framework for improving the quality of flue gas flow rate monitoring for emissions reporting and other purposes.

In March 2017 a technical report was published PD CEN/TR 17078:2017 Guidance on the application of EN ISO 16911-1

The Technical Report does not follow the numbering of EN ISO 16911-1:2013; however for easier handling it uses the same headings and sub-headings as EN ISO 16911-1:2013. It does not repeat text, tables or diagrams from EN ISO 16911-1:2013, instead it refers to the relevant sections of the Standard.

It is therefore essential that the user has a copy of the Standard to refer to. For sections of the Standard where this Technical Report does not provide any text or guidance it is deemed that the relevant section does not require any additional clarification.

The Source Testing Association (STA)

The Source Testing Association (STA) was established in 1995. Its membership comprises representation from process operators, regulators, equipment suppliers and test laboratories. The STA is a non-profit making organisation.
The STA is committed to the advancement of the science and practice of emission monitoring and to develop and maintain a high quality of service to customers.
Its aims and objectives are to:

- Contribute to the development of industry standards, codes, safety procedures and operating principles
- Encourage the personal and professional development of practicing source testers and students
- Maintain a body of current sampling knowledge
- Assist in maintenance of a high level of ethical conduct
- Seek co-operative endeavours with other professional organisations, institutions and regulatory bodies, nationally and internationally, that are engaged in source emissions testing

The Association's headquarters is based in Hitchin, Hertfordshire, with meeting rooms, library and administration offices.
The Association offers a package of benefits to its members that includes:

- Technical advice relating to emission monitoring
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Tel: +44(0) 1462 457535 • **www.s-t-a.org** • **General enquiries:** sam@s-t-a.org
• **Technical support:** andycurtis@s-t-a.org • **Website enquiries:** steve@s-t-a.org

Author Contact Details

David Graham and Jonathan Spence
Uniper Technologies

- Email: David.Graham@Uniper.Energy
- Tel: +44 (0) 7921 491164
- Web: www.uniper.energy

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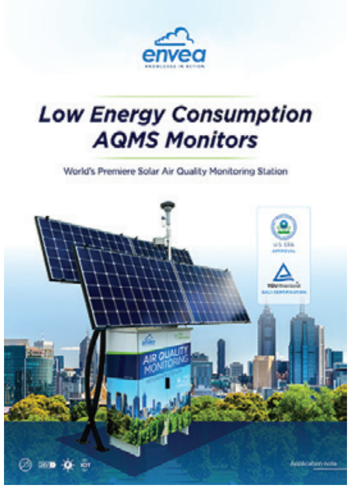
World's first solar-powered air quality monitoring station



ENVEA has inaugurated in July the world's premiere solar powered criteria pollution monitoring station in its headquarters in Poissy, France (Paris region).

The Solar AQMS is an all-in-one and self-sufficient air quality monitoring station that can be installed anywhere, even in isolated locations. Able to withstand high temperatures without air conditioning and without connection to the electricity grid, it operates 24 hours a day, 7 days a week, powered solely by solar energy. This pilot monitoring station contains the well-known eco-designed e-Series analysers. Certified QAL 1 and US-EPA approved, they offer the best metrological performance for continuous monitoring of CO, O_3, NO_2, SO_2, and fine particles PM10 / PM2.5.

Eco-designed, this new series of gas and particle analysers with very low energy consumption, have been recently enhanced to withstand high ambient temperature variations and support 24 V power supply. Thanks to these unique features, the analysers can endure temperatures up to 50-55°C without air conditioning.

In addition to these advanced technologies, the Solar AQMS station is equipped with e-SAM and XR©, ENVEA's data acquisition and handling systems. They feature centralised data management in the cloud for processing, analysis and reporting, threshold alerts, as well as remote energy management and station control (calibration, diagnostics, etc.).

This innovation represents an important breakthrough for governments and institutions worldwide struggling to set up supportive measures and regulations to curb air pollution. It will support the air quality measurement across the developing world struggling with the reliability of their energy supply, as well as the forward-thinking 'smart cities' looking to re-define their energy mix and supporting renewables on the grid. The very low energy consumption of such a station, its ease of integration into the urban or rural landscape and advanced connectivity and proactive interactivity with operators, are making it perfectly suited for remote areas as well as for smart-cities.

Today, more than 20,000 traditional pollution measurement stations connected to an electricity grid are located around the world. For example, the upgrading of the 670 measuring stations spread over France would save some 20,000 kWh/day, the equivalent of the annual consumption of nearly 1,500 households.

More information online: ilmt.co/PL/yOao

For More Info, email:
50331pr@reply-direct.com