Environment Agency Method Implementation Document for EN 16911-2

Stationary source emissions - Manual and automatic determination of velocity and volume flow rate in ducts Part 2: Automated measuring system

The Environment Agency recognises that European and International standards may need supplementing by Method Implementation Documents (MIDs) to make sure they are being implemented consistently.

This MID supplements EN 16911-2:2013. The clause numbers in this document follow those of EN 16911-2, although the text from the standard is not repeated in this document.

1 Scope

This MID has been developed to support the calibration of continuous emission monitoring systems (CEMS) used to measure flow.

Flow CEMS are referred to as automated measuring systems (AMS) in EN 16911-2. The term AMS is also used in this MID. EN 16911-2 supplements the requirements of EN 14181 which defines Quality Assurance Levels (QALs) for AMS.

Information is provided for accredited test laboratories that employ a standard reference method (SRM) according to EN 16911-1, and plant operators, in relation to their obligations to calibrate AMS according to EN 16911-2.

2 Normative references

The following has been published since the publication of EN 16911-2:

PD CEN TR 17078:2017: Stationary source emissions: Guidance on the application of EN ISO 16911-1.

3 Terms, definitions

No additional information.

4 Symbols and abbreviated terms

No additional information.

5 Principle

5.1 General

No additional information.

5.2 The importance of minimising systematic errors

Further guidance on achieving low systematic uncertainty when using a point velocity SRM is given in PD CEN TR 17078:2017.

5.3 Relationship to EN 14181

No additional information.

6 Type testing, quality assurance Level 1 data

No additional information.

7 Selection of automated measuring system location

7.1 General

A one-off pre-investigation is strongly recommended prior to installing new flow AMS and can be useful prior to calibrating existing AMS or for resolving poor AMS performance. Provided that the AMS selection complies with EN 16911-2, a reduced scope QAL2 and annual surveillance test (AST) may be conducted. This has the advantage of only requiring testing at a reduced plant load once.

The pre-investigation is intended to be a guideline to operators to enable them to make good engineering decisions in relation to the siting and installation of AMS. However, a retrospective pre-investigation can also be useful because it enables QAL2 tests and ASTs to be performed, with a reduced number of test points (referred to as type 1), provided that the AMS is selected and installed according to Table 3 of EN 16911-2 or the manufacturer of the AMS provides a written recommendation confirming its suitability. If one of these conditions is not met, a more extensive QAL2 or AST shall be performed (this is referred to as type 2). A retrospective pre-investigation can also assist with understanding and rectifying QAL2 and AST failures.

7.2 Selection based upon pre-investigation

Guidance on the selection of the primary (P) and secondary (S) monitoring paths is given in Annex C of EN 16911-2 for both circular and rectangular ducts. Both paths should normally pass through the centreline of the duct with P containing the maximum anticipated or measured velocity, and S perpendicular to P.

EN 16911-2 requires installation according to the manufacturer’s instructions or in consultation with the manufacturer or their representative. If the pre-investigation, or later QAL2 testing, indicates that the existing or proposed measurement location is unsuitable for the specified AMS then the operator should share the results of the pre-investigation with the AMS installer or manufacturer when relocating or replacing the AMS.

Reporting of velocity profile characterisation, as described in Annex F of EN 16911-2, is required for P and S monitoring paths, and the installed AMS path, if different. For rectangular ducts, the test laboratory may choose to also report the results for any additional or alternative paths.

7.3 Selection based upon a predictable flow profile

No additional information.

7.4 Qualifying the automated measuring system calibration through a type 2 quality assurance level 2 procedure

No additional information.

7.5 Ports and working platforms

The sample ports used for the pre-investigation may be different to those used for the QAL2 calibration. The sample ports used for the QAL2 calibration can be located:

- further downstream of the AMS (see section 9.3 below)
- at different paths within the SRM measurement plane used for the pre-investigation.

The pre-investigation requires that the SRM measures along the AMS' P and S monitoring paths (see Annex C of EN 16911-2) but without measurable cross-interference. This can be achieved by:

- using the AMS ports, after removing the AMS to accommodate the SRM
- using an upstream SRM measurement plane that contains the P & S paths
- using a downstream SRM plane that contains the P & S paths but checking for cross-interference.

Dedicated SRM test ports used for the pre-investigation should then be located close to the proposed or existing AMS location, typically at an axial location within 0.5D or 1m of the AMS, whichever is larger. An additional SRM port is required for measuring the velocity at a fixed point during the duct velocity traverse, noting that an installed AMS shall not be used to provide the reference velocity.

If a reference port is not available, a reference point may be selected from S when traversing P and vice-versa. The results are then analysed and reported for each half traverse (P and S), using separate reference points to correct each path, in the usual way.

If the SRM ports are upstream of the AMS then it can be assumed that the AMS does not interfere with the SRM pre-investigation. If the SRM ports are downstream of the AMS then there shall be a check for cross-interference. If there are velocity discontinuities (that is step changes) in the SRM velocity profile that are aligned with the upstream AMS, then the AMS shall be removed and the pre-investigation repeated.

AMS down-time associated with temporary AMS removal for the purposes of conducting a pre-investigation shall be classed as AMS unavailability unless the testing can be conducted within the permitted time allowed for maintenance of the

AMS. This can be avoided by using a standby AMS when the duty AMS is out-of-service and the use of a duty AMS when the standby AMS is out of service.

8 Pre-investigation of flow profile

8.1 General

A pre-investigation is strongly recommended before a new flow monitor is selected and installed. This provides information on the type of monitor to be installed (guidelines are given in Table 3 of EN 16911-2), and on the QAL2 and AST measurement strategy. The pre-investigation is conducted at the plant maximum and minimum flow rates. The pre-investigation therefore requires the operator to reduce the plant flow to at least the 10th percentile flow that occurs during normal operation (excluding start-up and shut-down).

The 10th percentile flow can be calculated as follows:

i) rank the measured short-term flow averages (half-hourly or hourly) for one year of operation from the highest to the lowest values
ii) discard the values that relate to start-up and shut-down
iii) select the load below which there are 10% of the short-term averages.

Alternatively, apply the Excel function “Percentile(Array,0.1)” to the array of short-term flow averages from periods of normal operation.

The most recent complete calendar year of operation shall be used for this assessment unless this is shown to be atypical, in which case a previous year may be selected, and the justification recorded in the test laboratory report. Periods of normal operation may be selected based on a plant run signal, which for example considers the thermal state of the plant and the admittance of waste fuel.

If there is insufficient operational data to make this assessment, the lowest flow level can be estimated from plant design data and the pre-investigation may be done when conducting plant performance or acceptance tests.

For a plant that operates mostly at maximum flow, the 10th percentile flow will be at a high flow condition. This means it is sufficient to perform the pre-investigation at maximum flow. In this case, the reproducibility of the flow profile shall be assumed to be zero.

However, if the 10th percentile flow is less than 80% of maximum flow then the operator is required to perform the pre-investigation at or below the 10th percentile flow and preferably at the plant minimum load condition that was demonstrated during plant guarantee testing. If it is not possible to run the plant at the required low flow condition, the operator may instead choose to base the assessment on a computational fluid dynamics (CFD) study (see clause 8.3), having performed a pre-investigation at the maximum flow to check that the CFD model delivers a reasonable prediction.

8.2 Pre-investigation measurement

8.2.1 General

No additional information.

8.2.2 Measuring flow profiles in a duct

Guidance on the selection of P and S monitoring paths is given in Annex C of EN 16911-2 for both circular and rectangular ducts. Guidance on correcting the flow profile with the reference point flow is given in Appendix F of EN 6911-2 and clause 6.10 of TR 17078.

8.2.3 Measurement method

Guidance on correcting the flow profile with the reference point flow is given in Appendix F of EN 16911-2 and clause 6.10 of TR 17078.

8.3 Pre-investigation by computational fluid dynamics (CFD)

For a new plant, during the design phase, the pre-investigation may be carried out by means of a CFD study (clause 8.3) prior to performing the pre-investigation during commissioning.

For an existing plant, where a minimum flow measurement is required but it is not possible to measure at minimum flow, CFD can be used to assess the minimum flow profiles. In this case, the CFD model shall be checked by comparing the measured normalised axial velocity profiles at maximum flow with the calculated axial velocity profiles.

The CFD axial velocity profiles at the proposed AMS location(s) shall be used to calculate the crest factor, skewness, and reproducibility at the maximum and minimum plant flow (see clause 7.4). In the case of shared stacks, this shall be extended to cover all possible stack inlet combinations, associated with different combustion lines being operational.

For all the proposed AMS monitoring point or path(s), selected from Annex C, the CFD model shall be used to develop a QAL2 relationship in which the CFD average predicted velocity is taken to be the SRM reading, and the predicted point, or line-of-sight average, is taken to be the AMS reading. The calculation of the point or line-of-sight average shall consider the proposed AMS measurement principle. The optimum monitoring path(s) shall then be selected to give an acceptable linear QAL2 calibration, that is, the R^2 criterion shall be fulfilled.

In the case of multiple stack inlets, the CFD modelling shall be used to determine if different QAL2 calibration relationships are needed for the different modes of plant operation for the selected monitoring path(s).

8.4 Automated measuring system selection guide

The pre-investigation report shall include the suggested measurement type and the comments provided in Table 3 of EN 16911-2. If the AMS is not selected according to Table 3 then, as an alternative, the AMS installer or manufacture may provide a written recommendation confirming AMS suitability and this shall be recorded in the pre-investigation report.

If the AMS is not selected or installed according to Table 3 or does not have a recommendation from the manufacturer or installer, then a type 2 QAL2 and AST shall always be performed. For installed AMS, the location and type of the AMS shall be compared with the recommendations in Table 3. Following a QAL2 or AST failure, that cannot be resolved by AMS repair or re-testing, possibly using a different SRM, the AMS shall be upgraded in line with the recommendations in Table 3.

8.5 Quality assurance level 2

No additional information.

9 Calibration and validation of the automated measuring system (quality assurance level 2 and annual surveillance test)

9.1 Selection of calibration method

If a pre-investigation has not been performed, or the AMS is not then selected or installed according to Table 3 of EN 16911-2 or according to the manufacturer's written recommendations, the type 2 QAL2 requires the operator to reduce the plant load to at least the 10th percentile flow that occurs during normal operation, excluding start-up and shutdown (see section 8.1). For a plant that operates mostly at maximum flow, this percentile flow will be at a high flow condition. This means it is sufficient to perform the QAL2 at high flow conditions whilst still aiming to provide the maximum possible variation that can be achieved during normal operation within the test period.

However, if the 10th percentile flow, as calculated according to section 8.1, is less than 80% of maximum flow then the operator is required to incorporate at least one low flow point, at or below the 10th percentile load, within the calibration.

9.2 Selection of calibration method, if calculation methods are used

9.2.1 Fuel based

When the AMS is based on a calculation method, the QAL2 is used for verification only, the QAL2 factors are not applied. Instead, the AMS calculation shall be verified, which means the AMS shall pass both the QAL2 variability test and the AST test of validity (as applied to the QAL2 data). At subsequent ASTs, the AMS is required to pass both the AST variability test and the AST test of validity (as applied to the AST data). The value of σ_0 used in these tests is adjusted as described in section 9.10 below. This approach requires the absolute agreement between the AMS calculation and the SRM measurement to be within the defined validity criteria.

Prior to verification, the calculation inputs and the calculation procedure should be checked by the operator to make sure that they meet the requirements of EN 16911-1 (Annex E).

The dry stack flow, at 273.15K and 101.3 kPa, can be calculated from the fuel consumption as follows:

Stack flow (m^3/s) = fuel flow (kg/s) * net calorific value (MJ/kg) * fuel factor (m^3/MJ)

The fuel factor specified in EN 16911-1 (Annex E) is first corrected to the reference oxygen concentration used for emissions reporting. Any consistent units can be used for the fuel flow and the net (lower or inferior) calorific value. For natural gas fired plant, the fuel flow and net calorific value shall be in the same units, for example, kg/s and MJ/kg or Sm^3/s and MJ/Sm^3 (referenced to 15°C) or Nm^3/s and MJ/Nm^3 (referenced to 0°C).

Alternatively, the dry stack flow can be calculated from the plant output:

Stack flow (m^3/s) = [output (MW) / (efficiency (%) /100%)] * fuel factor (m^3/MJ)

The plant output and efficiency shall be on the same basis, for example, net (exported or sent out) electricity or gross (generated) electricity, or thermal output.

On an annual basis, a manual calculation check of the data acquisition and handling system (DAHS) reported stack flow rate, based on the DAHS input data, shall be performed by the operator or the test laboratory, to demonstrate that the calculation has not been modified.

9.3 Calibration procedure

General

Whilst the pre-calibration velocity survey is a separate activity, that serves a different purpose to the QAL2 testing, the test laboratory may add pre-investigation results to QAL2 test results, if they were obtained using the same SRM test ports. This potentially enables a low flow test condition to be included in the QAL2 and AST test results. Both sets of measurements shall be conducted after the QAL2 functional tests. However, the required number of QAL2 tests shall be conducted as specified in Table 4 of EN 16911-2 with any pre-investigation results added to the QAL2 data set.

The test laboratory that does the QAL2 may use the results from a pre-investigation that was done by a different test laboratory (both laboratories shall be MCERTS accredited for the measurement of flow according to this MID).

Pre-investigation data shall only used in a QAL2, if the QAL2 tests are done within 6 months of the pre-investigation.

Point velocity SRM

A fixed point SRM reference measurement is not required when performing QAL2 or AST tests but this is recommended if the plant flow is expected to be variable. This should be established when planning the test campaign and recorded in the site-specific protocol.

EN ISO 16911-1 recommends that the tangential method in EN 15259 is used for determining the location of sample points and states that the central point in the general method is not recommended for determining the average flow in the duct.

For circular ducts of diameter (D) < 0.35m, single point sampling is allowed provided that the following conditions are satisfied. According to ISO 7145, a probe can be located on the centre-line of the duct and multiplied by a correction factor to obtain the average velocity. The correction factor is best obtained by performing a more detailed one-off survey of the duct but, if that is not feasible, multiply the centre-line velocity by 0.85 to obtain the average velocity. ISO 7145 recommends that the sample plane is ≥ 25 diameters of straight duct downstream of the nearest disturbance when using this approach.

Alternatively, ISO 7145 recommends that the single point is located at 0.121*D from the wall to measure the average velocity directly but also recommends that the sample plane is ≥ 50 diameters of straight duct downstream of the nearest disturbance when using this approach.

If the available straight lengths of duct are not available, then the number of sample points shall be increased to a total of 4 and located according to EN 15259 (tangential method).

Pitot SRM

QAL2 and AST calibration of flow AMS shall not be combined with iso-kinetic testing, such as for particulates. The flow calibration is a separate activity that requires implementation of the flow SRM in full accordance with EN 16911-1 and, in the case of point velocity SRM measurements, following the guidance given in TR 17078.

Pitot SRM measurements can be affected by swirling (tangential) flow which causes the pitot to over-read. In highly swirling flows (> 15° swirl angle) an advanced 3D pitot or a tracer method is more appropriate. However, in low to moderately swirling flows the accuracy of pitot readings may be improved by applying the cosine correction (see EN 16911-1, section 9.3.5).

Ports and working platforms

The SRM test ports may be co-located with the AMS port(s), typically at an axial location within 0.5D or 1m, although a greater separation is acceptable. QAL2 testing may also be conducted at a different downstream location from the AMS. For example, an AMS may be in a ground level rectangular duct, whereas the SRM sampling location may be in the stack. Where locations are separated from each other, a representative oxygen measurement shall be performed at the SRM location to enable the stack flow rate to be corrected to AMS or reference conditions.

If the AMS and the SRM are not axially aligned, then it can be assumed that there is no cross-interference between the AMS and the SRM. For example, in a circular duct, the AMS may be rotated around the stack when compared with the SRM measurement plane. This is especially beneficial when the AMS is an averaging pitot.

The following checks shall be done when the AMS and the SRM are axially aligned:

- When the SRM is located upstream of the AMS, cross-interference shall be checked by fully inserting the SRM probe into the duct whilst monitoring the AMS response for a step change. Advice shall also be requested from the AMS installer or manufacturer because certain types of AMS are more prone to cross-interference than others, for example, vortex shedding probes are especially prone to local flow disturbances.
- When the SRM is located downstream of the AMS then the first measured SRM velocity profile shall be inspected for velocity discontinuities (that is step changes) that are aligned with the upstream AMS location.

If cross-interference is apparent then the AMS or the SRM shall be relocated or the AMS shall be changed for a less sensitive type, or a different SRM employed, noting that most cross-interference issues are associated with point velocity SRM.

Tracer dilution or transit time SRM are generally unaffected by cross-interference. In the case of a tracer dilution SRM, again the tracer concentration measurement can be located further downstream of the AMS to promote mixing of the tracer gas with the flue gas. In the case of a tracer transit-time SRM, the duct cross-section should ideally not vary between the upstream and downstream sensors.

Test duration

EN 16911-2 specifies a minimum test duration of 5 hours for a QAL2. This MID specifies a minimum test duration of 3 hours for an AST.

The measurement duration is from the start of the hour within which the first test is conducted until the end of the hour within which the last test is conducted. EN16911-2 states that QAL2 and AST tests shall be performed to obtain data points that are evenly spread out over the test duration. If technically feasible, the testing can therefore be performed in a day. The time taken to perform a single test depends on the SRM employed.

Tracer injections are rapid, such that a data point is obtained in seconds or minutes. It is not necessary to spread these measurements evenly across the test duration. The spread will depend on plant scheduling and the need to capture as wide a range of plant flow conditions as possible.

Point velocity traversing methods require more time to perform a duct traverse. It is also necessary to make sure that a stable reading is obtained at each grid point.

An average measurement shall be taken for at least 1 minute at each grid point but this may need to be extended depending on the local flow turbulence.

The time required to perform a single traverse depends on the duct size and the associated number of test points and this may be less than the sample averaging time specified in EN 14181 (that is less than 30 or 60 minutes). However, the traverse time shall not be less than 20 minutes, which means longer sample times at individual grid points when the total number of grid points is less than 20. Multiple traverses within the minimum test duration may be conducted back-to-back, provided they are evenly spread out.

Reporting

Flow QAL2 reports shall:

- state whether a pre-investigation has been performed
- reference the pre-investigation report
- re-state the suggested AMS measurement type and the comments provided in Table 3 of EN 16911-2, and refer to any written recommendation of AMS suitability from the AMS installer or manufacturer.

9.4 Functional tests

Functional tests may be performed by a suitably trained operator, test laboratory, AMS supplier, or another competent third-party. The functional tests, which are audited by the test laboratory, include linearity, response time, zero and span checks. Functional test results should be reported using a form that meets the requirements of Environment Agency Technical Guidance Note M20 and EN 14181.

In the absence of all or some of the functional tests and/or QAL3 capability, the manufacturer or the operator should specify the reasons for the inability to carry out each functional test and/or QAL3 and should provide a list of any alternative quality assurance and maintenance procedures. These should be reported along with the scheduled frequency of intervention. For example, in the case of a pitot AMS, the frequency of the field calibration check of the pressure drop sensor should be stated. Also, it may be possible to perform a zero and span check but there is no means of performing the linearity test.

The test laboratory shall audit the duct dimensions and the cross-sectional area that is used to report the volume flow rate. The operator should provide a drawing of the duct cross-section for inclusion in the test report. The test laboratory shall report both their own measured values and the audited values in the test report (that is both duct dimensions and cross-sectional area). If the cross-sectional area differs by more than 2% then the test laboratory shall recommend that the operator investigates and changes the duct area that is used for AMS reporting. A QAL2 data analysis conducted in volume flow units shall be repeated if the AMS duct area is revised.

EN16911-2 requires a one-off audit of the AMS configuration, including the geometrical configuration. The operator should supply any relevant AMS installation drawings or specification sheets to the test laboratory. The test laboratory shall check and record any geometrical factors within the AMS, including the diameter and the cross-sectional area at the AMS measurement plane. It is recommended that this is done during a service visit. Alternatively, a downloaded AMS configuration file (either electronic or hard copy) can be inspected to check the geometrical set-up with reference to the stack diameter.

The following are examples of information that shall be checked during the AMS audit and reported by the test laboratory:

- Probe AMS (pitot or anemometer point velocity measurement) - the distance from the inside wall of the duct to the measurement point, or the centre of the measurement volume.
- Averaging pitot AMS - the number and relative position of the pitot holes.
- Cross-correlation AMS - the vertical separation between the detectors.
- Cross-duct ultrasonic AMS – all geometrical set-up parameters such as the axial separation between the transducers.

The values of any geometrical parameters that are entered into the AMS and/or the DAHS shall also be checked annually and reported with reference to the manufacturer's specifications and requirements. This can be based on in-year service reports or configuration file downloads if the required information is readily available.

For a pitot AMS, the one-off audit shall include a check of the assumed density or molecular mass of the flue gas in addition to any other relevant parameters, for example, an assumed pressure and temperature. All assumed parameter values shall be checked against typical plant conditions and the comparison reported. The AMS pitot coefficient shall also be reported along with the formula relating velocity to ΔP from which it should be clear if the coefficient is within or outside of the square root term. Further investigation of the assumed values is required if there is a QAL2 or AST failure.

Any change in plant conditions or assumed values since the last QAL2/AST, with an influence on the flow monitoring result, for example, temperature, pressure, gas composition, ducting geometry needs to be considered and discussed with the operator annually as it may increase the risk of a QAL2 or AST failure.

9.5 Parallel measurements with a standard reference method

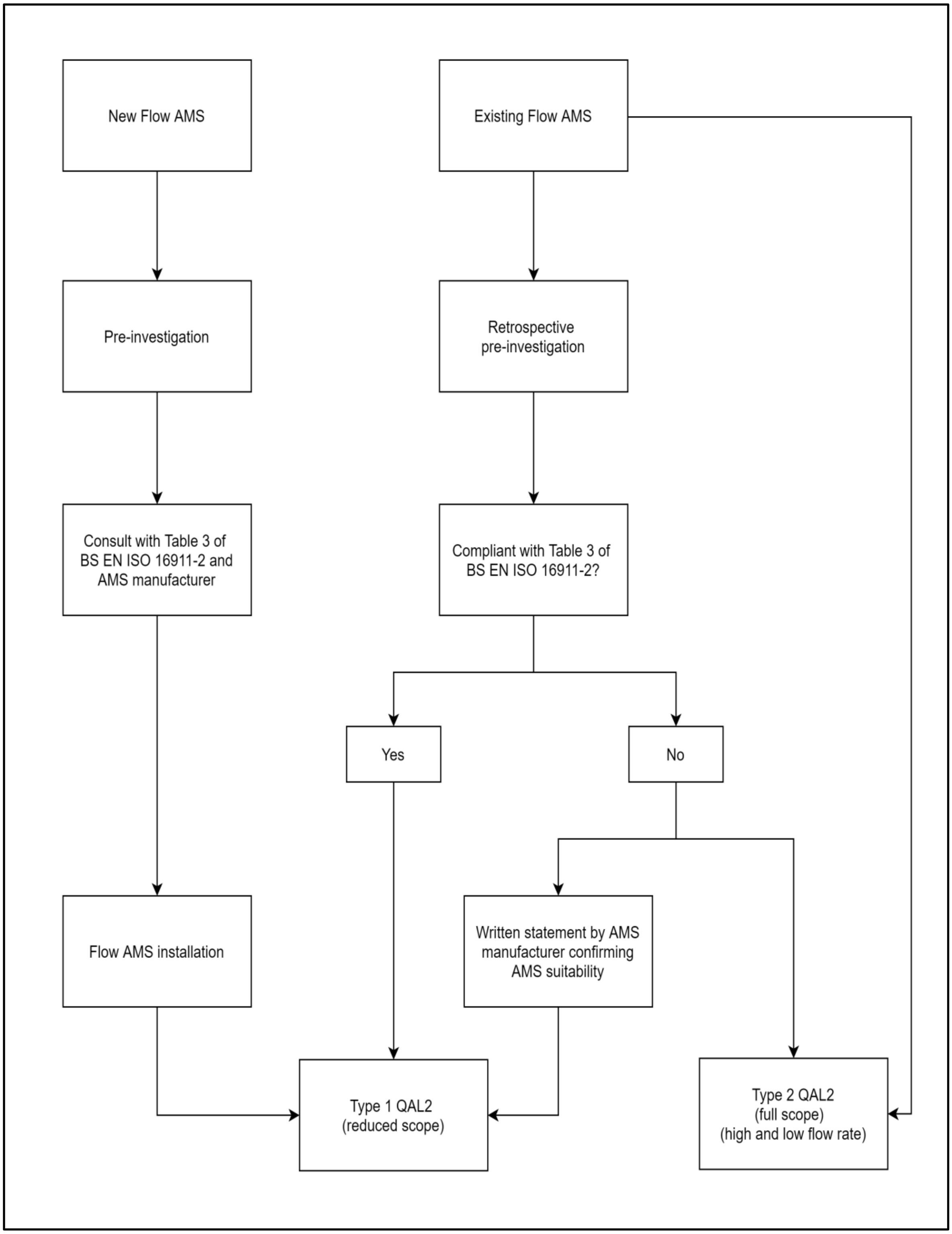
Results obtained from the SRM shall be expressed using the same measurement units and under the same conditions as reported by the AMS, that is, either m/s or m^3/s or m^3/h, regardless of AMS type. For AMS based on pressure differential measurement, the calibration relationship shall not be expressed in pressure units.

When the AMS corrects the flow to reference conditions but does not export the raw data, it is acceptable for the SRM results to be expressed at the same reference conditions, provided that the AMS is using live peripheral data to make the correction (temperature, pressure, O_2 and H_2O). In this case, the test laboratory shall confirm that the AMS corrections are correct. However, the operator should consider updating the system to enable the AMS to export raw data with the corrections to reference conditions then being performed in the DAHS (as suggested by EN 17255-1).

When the AMS is based on a calculation method, the flow rate is normally calculated at the same reference conditions that are used for reporting emission concentrations, in which case the SRM results shall be expressed at the same reference conditions.
Table 4 of EN 16911-2 provides the minimum numbers of paired data points (traverses if a point velocity technique is used) and the upper and lower limit of the calibration range for a QAL2 calibration. The approach specified in this table may be modified based on the information provided in this MID. A summary of the modified approach is provided in Flow chart 1 of this MID.

If a pre-investigation has not been performed, the standard places requirements on the upper and lower limit of the calibration range that shall be met during the QAL2. Data that are above or below these upper and lower calibration limits shall still be used in the QAL2 calibration.

Flow chart 1 – selection of QAL 2 approach



9.6 Wall effects

For a point velocity SRM, EN 16911-1 (section 10.4) allows the operator to select a wall adjustment factor (WAF) to be applied to the SRM results to account for the velocity decay close to the duct wall. The WAF can either be based on a default value or additional near-wall velocity traverses, which are determined at the highest QAL2 flow rate. This exercise only needs to be completed once, unless the velocity profile is altered, for example by changes in the ductwork. Further details are given in EN 16911-1 which refers to the relevant US EPA methods. For circular ducts, a default WAF of 0.99 can be assumed for industrial stacks or 0.995 for smooth walled ducts. For rectangular ducts, the approach defined in US EPA CTM-041 can be employed.

For a QAL2 calibration, the test laboratory shall apply the specified WAF to the SRM results. The approach taken should be agreed with the operator. It shall be recorded in the site-specific protocol and the test report. The WAF is not applied to AMS results. If a WAF has been applied by mistake then it shall be removed from the AMS results, prior to the QAL2 data analysis.

The tracer dilution SRM does not require a WAF to be applied since the volume flow rate is determined directly. The tracer transit-time SRM does not require a WAF to be applied since the bulk average velocity is determined directly.

9.7 Automated measuring system flow calibration procedure with transit time tracer

No additional requirements.

9.8 Data evaluation

Regardless of AMS type, SRM results shall be expressed using the same measurement units and under the same reporting conditions as output by the AMS, either m/s or m^3/s or m^3/h. For AMS based on pressure differential measurement, the calibration relationship shall not be expressed in pressure units.

Exceptions are considered in 9.5 above.

9.9 Calibration function of the automated measuring system and its validity

9.9.1 General

Following a QAL2 or AST failure, that cannot be resolved by AMS repair or re-testing, or by using a different SRM, the AMS shall be upgraded in line with the recommendations of Table 3 of EN 16911-2.

9.9.2 Linear calibration function (method D)

A method d calibration may still be used even if it is not possible to demonstrate linearity, that is, the CEMS does not have the functionality. If any of the QAL2 data points do not lie within 10% of the calibration line, having removed outliers as defined in EN 14181, this shall be investigated and corrective action taken, for example, CEMS replacement.

9.9.3 Polynomial calibration function

A linear calibration function is preferred. There shall be an explanation of non-linear behaviour before considering the use of a polynomial calibration function, with reference to the pre-investigation (if performed).

A polynomial calibration function shall only be considered if the R^2 test fails (section 9.12), having already applied a linear calibration function according to method D (section 9.9.2), and having checked the linear performance of the AMS. The polynomial function shall then pass the R^2 test and the DAHS shall comply with Annex D of EN 16911-2.

9.10 Calculation of variability

The threshold value of 10 m/s shall be converted into volume units using the stack dimensions at the AMS location. This value shall be compared to 120% of the maximum calibrated (or verified) AMS measured flow rate during the QAL2 test. The greatest of either of these shall be used as the surrogate ELV. The surrogate ELV is applicable for both the QAL2 and the AST.

A σ_0 value of 5% of ELV shall be used for the calculation of variability instead of 4%. The associated expanded uncertainty is 10% of ELV which is consistent with QAL1 certification under EN 15267-3. When the AMS is based on a calculation method, σ_0 is evaluated at the same reference conditions as the flow calculation.

9.11 Test of variability and annual surveillance test of validity of the calibration function

A σ_0 value of 5% of ELV shall be used for the calculation of variability and validity instead of 4%. The associated expanded uncertainty is 10% of ELV. In relation to the EN 14181 formula $\sigma_0 = P\,E / 1.96$, the value of P is therefore 10%.

In the case of a QAL2 failure, first check that the response time of the AMS has been correctly considered in the data analysis. Then examine the performance of the AMS and the SRM.

For certified AMS, the QAL3 performance and the results of functional tests should be examined first. For uncertified AMS, the correct functioning of the AMS should be established by following the recommendations of the manufacturer.

If the high variability is mostly caused by the AMS then the AMS should be repaired, or replaced with a different AMS type, prior to re-testing. It can be useful to check that the AMS performance was consistent with historic plant measurements, for example, by plotting flow verses plant load for a historic period and comparing this with the QAL2 test period. If duty and standby AMS are installed, the assessment should include a comparison of both AMS; if the variability between the AMSs is low then the SRM is likely to be the source of the QAL2 variability.

If the variability is mostly caused by the SRM then an alternative SRM measurement approach should be considered. If the issue is related to the interaction between the flow field and the SRM, the selection of a different SRM measurement location should be considered.

If an AST fails, the above approach can be followed. However, the AST variability pass criterion is easier to pass than the QAL2 variability criterion, so any differences between the original QAL2 and the AST testing should first be investigated. Failure of the AST test of validity implies a shift in performance of the AMS or the SRM. Comparison of duty and standby AMS performance can be useful in diagnosing issues.

9.12 Test of R^2

The standard states that, if a pre-investigation has been performed, fulfilment of the R^2 criterion of >0.90 is not required if the method D calibration is based upon a tight data cluster and both the AMS and SRM data spreads (maximum - minimum) are both less than 15% of the corresponding average flow during the calibration. This provision also applies when a pre-investigation has not been performed, provided that the linearity requirement in 9.9.2 is met.

Otherwise, the R^2 test shall not include the zero point when implementing method D.

9.13 Quality assurance level 2 and annual surveillance test report

The test laboratory shall report the make, model and type of AMS in the QAL2 and AST test reports.

10 Commissioning documentation

No additional information.

11 On-going quality assurance during operation (quality assurance level 3)

In the absence of all or some of the QAL3 capability, the manufacturer or the operator should specify the reasons for the inability to carry out the QAL3 and should provide a list of any alternative quality assurance and maintenance procedures.

If no QAL3 procedure is specified, the test laboratory shall describe the checks and maintenance that are performed by the service engineer or operator and the associated frequency. For example, in the case of a pitot AMS, the frequency of the field calibration check of the pressure drop sensor shall be stated.

12 Assessment of uncertainty in volume flow rate

No additional information.

Annex A (informative) **Example of calculation of the calibration function (data from tests in Copenhagen and Wilhelmshaven)**

Annex B (informative) **Flow profile characteristics**

Annex C (informative) **Determination of measuring points and/or paths**

Annex D (normative) **Treatment of a polynomial calibration function**

Annex E (normative) **Values of *k*v(*N*) and *t*0,95(*N* − 1)**

Annex F (informative) **Example of a pre-investigation measurement**

Annex G (informative) **Computational fluid dynamics issues**

Annex H (informative) **The use of time of flight measurement instruments based on modulated laser light**

Annex I (informative) **Relationship between this International Standard and the essential requirements of EU Directives**

No additional information to the Annexes A - I.

Bibliography

ISO 7145:1982 Determination of flowrate of fluids in closed conduits of circular cross-section — Method of velocity measurement at one point of the cross-section.

EN 17255-1:2019 Stationary source emissions - Data acquisition and handling systems - Part 1: Specification of requirements for the handling and reporting of data.