Flue gas flow rate measurement for verifying continuous monitoring at power stations according to EN ISO 16911

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When is flue gas flow monitoring required?

- For Pollution Inventory (E-PRTR) reporting ...

  Typically the case for waste incineration plant where…

  Mass emissions reporting for E-PRTR may not be subject to specific compliance requirements (MS specific)

- When mass emissions compliance is required…

  Typically the case for large combustion plant in the…

  Transitional National Plan (TNP)

  Flow rate by measurement or calculation (stable fuel)

  Mass emission rate (mg/s)= Concentration (mg/m^3) * Flow (m^3/s)

  (Concentration and flow at the same reference conditions)

  Emission rate is also important for dispersion modelling

  Multiply by time period (in seconds) to obtain the mass released

    typically 1 hour or 30 min period: 3600s or 1800s

    1 mg = 10^{-3} g = 10^{-6} kg = 10^{-9} tonnes = 10^{-12} kt

- When mass emissions trading is required…

EU Emissions Trading System (EU ETS)

- ‘Measurement’ approach is allowed as an alternative to the ‘Calculation’ approach for CO_2 (required for N_2O)
- Measurement = CO_2 concentration (g/m^3) * flow rate (m^3/s)
- Reporting based on hourly average concentration (CO_2 + CO) g/Nm^3 and hourly emitted volume:

$$GHG_{\text{tot ann}}[t] = \sum_{i=1}^{\text{operating hours p.a.}} GHGconc_{\text{hourly } i} * \text{flue gas flow}_i * 10^{-6}[t/g]$$

- Flow can be measured or calculated
- Biomass CO_2 must be subtracted (calculation)
- Valid hour: at least 80% data capture (cf 66% LCP)
- Data loss: ≤ 5 consecutive days (cf 10 days/a LCP)
- Data substitution (cf none for LCP)
- Corroboration: against calculated emissions

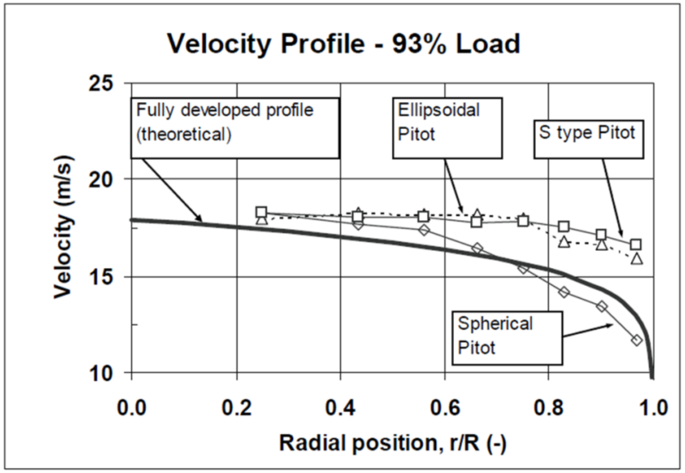
EN ISO 16911:2013

Stationary source emissions- Manual and automatic determination of velocity and volume flow rate in ducts

EN ISO16911 Part 1 Manual Reference Method

Allowed measurement techniques for flow calibration/verification

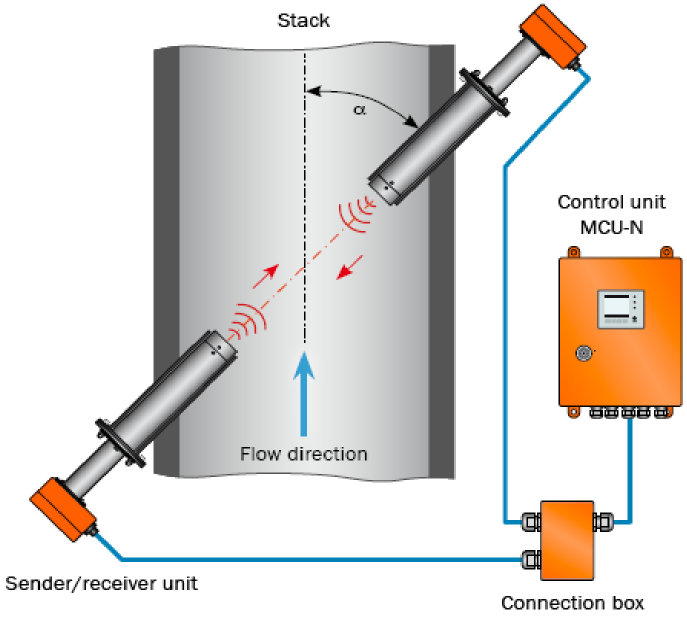
- Point velocity measurement (20 point survey on 2 diameters):
  - Pitot tubes (ΔP) (L, S, 2D, 3D)
  - Vane anemometer (direct V)
- Tracer dilution technique
- Tracer transit time technique



Basic approach

- Any technique can be used for flue gas flow calibration
- Uncertainty budget required and an approach defined for all methods
- The systematic uncertainty of the reference method must be assessed
- Duct diameter/area measurement is needed (except tracer dilution)
- Wall effects are required as per US EPA M2H (except tracer methods)

EN ISO16911 Part 2 Automated methods



Sick ultra-sonic meter

Performance based standard (QAL1)

- Techniques not prescribed (T, P, C ..)
- Cross stack and point techniques

Pre installation study

- Requirements on flow profile
- Stability of profile is important

Calibration against manual methods (QAL2)

- Usually wide range of flow not achievable
- Reduced number of points if flow profile checked (9 instead of 15)

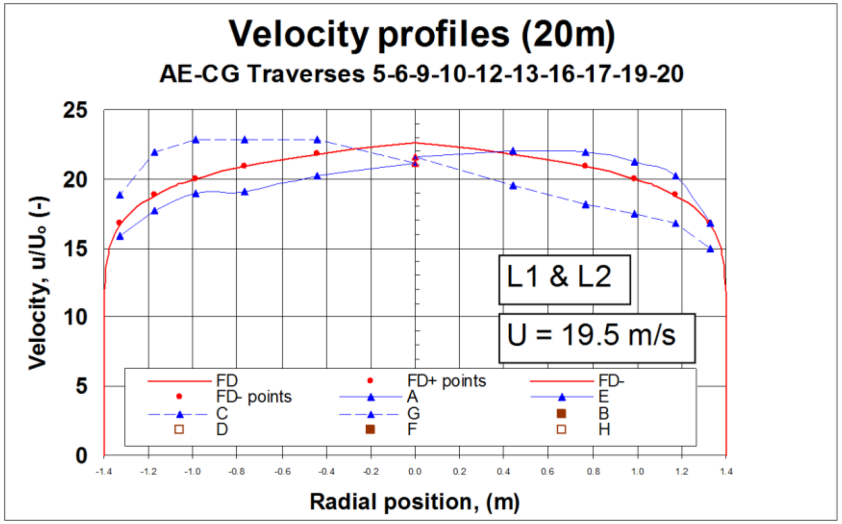
Ongoing quality assurance (QAL3)

- Flow reference material used to test as much of AMS as possible
- The procedure used to test parts of analyser not challenged by reference material shall be assessed and documented

Pre-investigation of flow profile

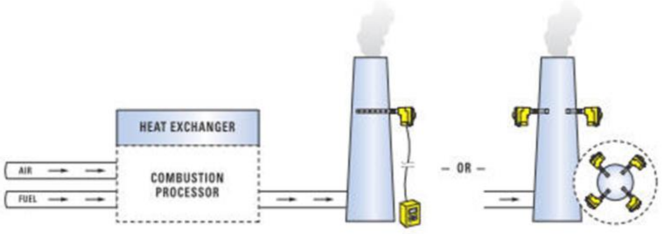
Assuring correct installation by strongly recommending a pre-investigation of the flow profile (at least min/max flow rates)

- If done: Simpler QAL2 /AST (fewer points – reduced range)
- CFD study for new plant



Is the flow profile symmetric/uniform?
Crest factor describes max/min velocity ratio
Skewness describes asymmetry

Does the flow profile change?
Reproducibility of non-dimensionalised flow profile between min and max flow rates



QAL2 Calibration – Departures from EN 14181

- QAL2 test duration – at least one day (cf 3 days)
- ‘Daily Emission Limit Value’ = 1.2 * Max measured flow
- Method D introduced (calibration line forced through zero)
- $R^2 > 0.9$ (cf no requirement) ; σ_o = 4% (cf 10% for NO_x)
- Competent Authority may require another value for σ_0
- QAL2 variability requirement is stricter
- AST statistics: typically need agreement ± 6% year on year
- Need assessment of stack XS area and AMS installation
- Note - some instruments susceptible to flow disturbance

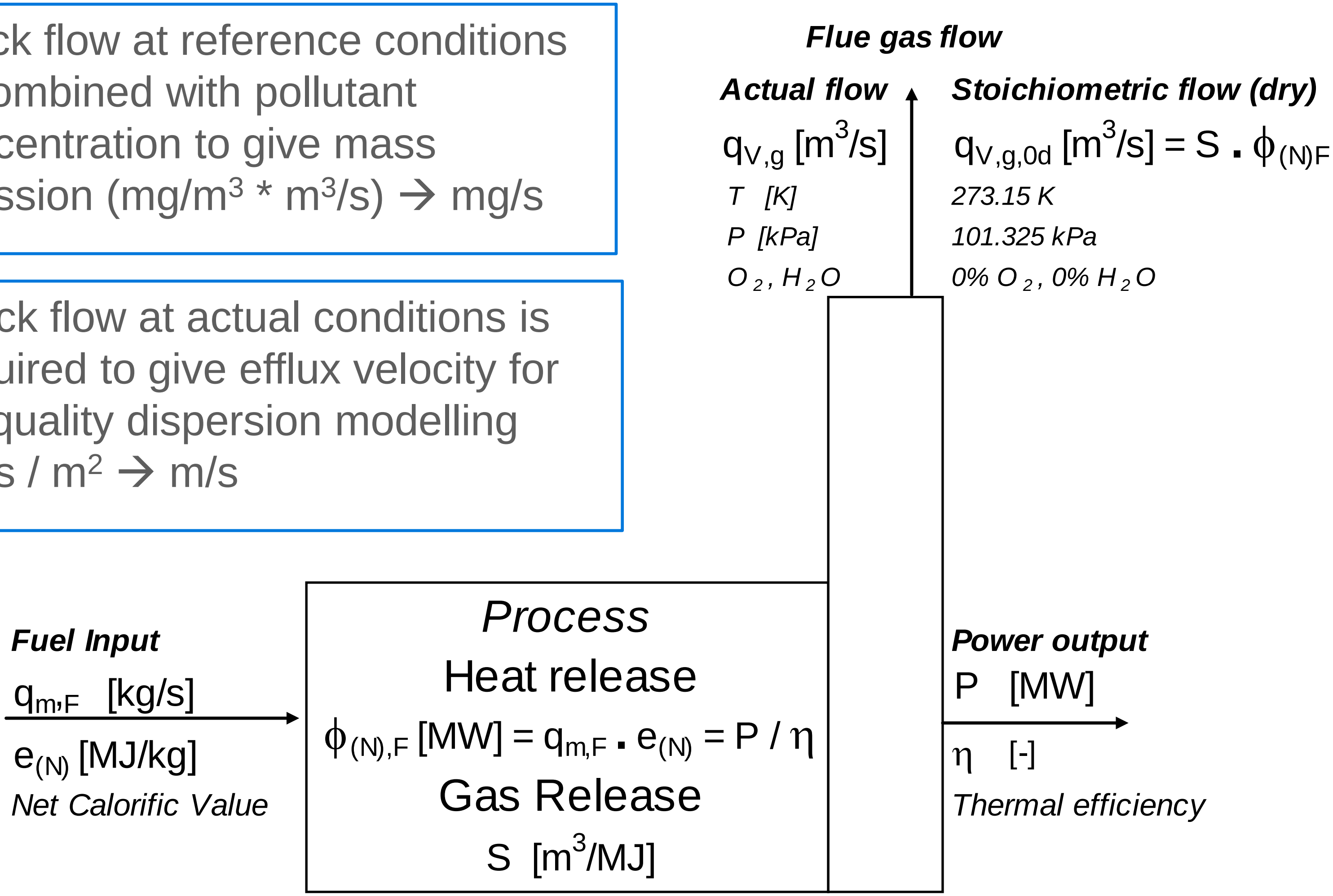
Flow calculation from Energy Input

- Calculation can be used for continuous monitoring
- Not dependent on plant geometry or flow profile
- Flue gas flow = Energy input (MJ/s) x Fuel factor (Nm^3/MJ)
- Fuel factors are defined for standard fuels
- Energy input calculated from fuel input or energy output
- Performance based approach with target uncertainty
- May require fuel flow meter upgrades
- QAL2/AST **verification** is required by means of stack testing (using SRMs)
- How to perform this verification is not specified

Part 1 Annex E (normative): Calculation of flue gas volume from energy consumption

Stack flow at reference conditions is combined with pollutant concentration to give mass emission (mg/m^3 * m^3/s) → mg/s

Stack flow at actual conditions is required to give efflux velocity for air quality dispersion modelling m^3/s / m^2 → m/s



Flue gas flow

Actual flow

$q_{V,g}$ [m^3/s]

T [K]

P [kPa]

O_2, H_2O

Stoichiometric flow (dry)

$q_{V,g,0d}$ [m^3/s] = $S \cdot \phi_{(N)F}$

273.15 K

101.325 kPa

0% O_2, 0% H_2O

Fuel Input

$q_{m,F}$ [kg/s]

$e_{(N)}$ [MJ/kg]

Net Calorific Value

Process

Heat release

$\phi_{(N),F}$ [MW] = $q_{m,F} \cdot e_{(N)} = P / \eta$

Gas Release

S [m^3/MJ]

Power output

P [MW]

η [-]

Thermal efficiency

VGB Research Project 379
Flue Gas Flow Rate Determination to EN ISO 16911

- Define a common approach to verifying flue gas flow rate calculation at power plant by means of field trials, data evaluation and interpretation of the standard
- Provide guidance on the choice of stack testing methods for use at coal and gas fired power plant, taking into account access restrictions at existing plant
- Define a common approach to the implementation, and Quality Assurance, of stack flow rate calculations
- Provide a tool for applying QA requirements to stack gas flow rate calculation in compliance with the appropriate standards (EN ISO 16911 and EN 14181)

Verification not Calibration

Define a common approach to verifying flue gas flow rate calculation

Propose that initial verification is based on:

1. AST Validity test - requires the mean deviation between the AMS and the SRM to be within a tolerance:

$$\left|\overline{D}\right| \le t_{0,95;\,N-1}\frac{s_D}{\sqrt{N}} + \sigma_0 \qquad \overline{D} = \frac{1}{N}\sum_{i=1}^{N} D_i \qquad \left|\overline{D}\right| \le 5\% - 10\%\ Q_{max}$$

2. QAL2 Variability test – requires that the scatter between the AMS and the SRM to be within a tolerance:

$$s_D \le \sigma_0\, k_v \qquad s_D = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(D_i - \overline{D}\right)^2} \qquad s_D \le\ \sim 5\%\ Q_{max}$$

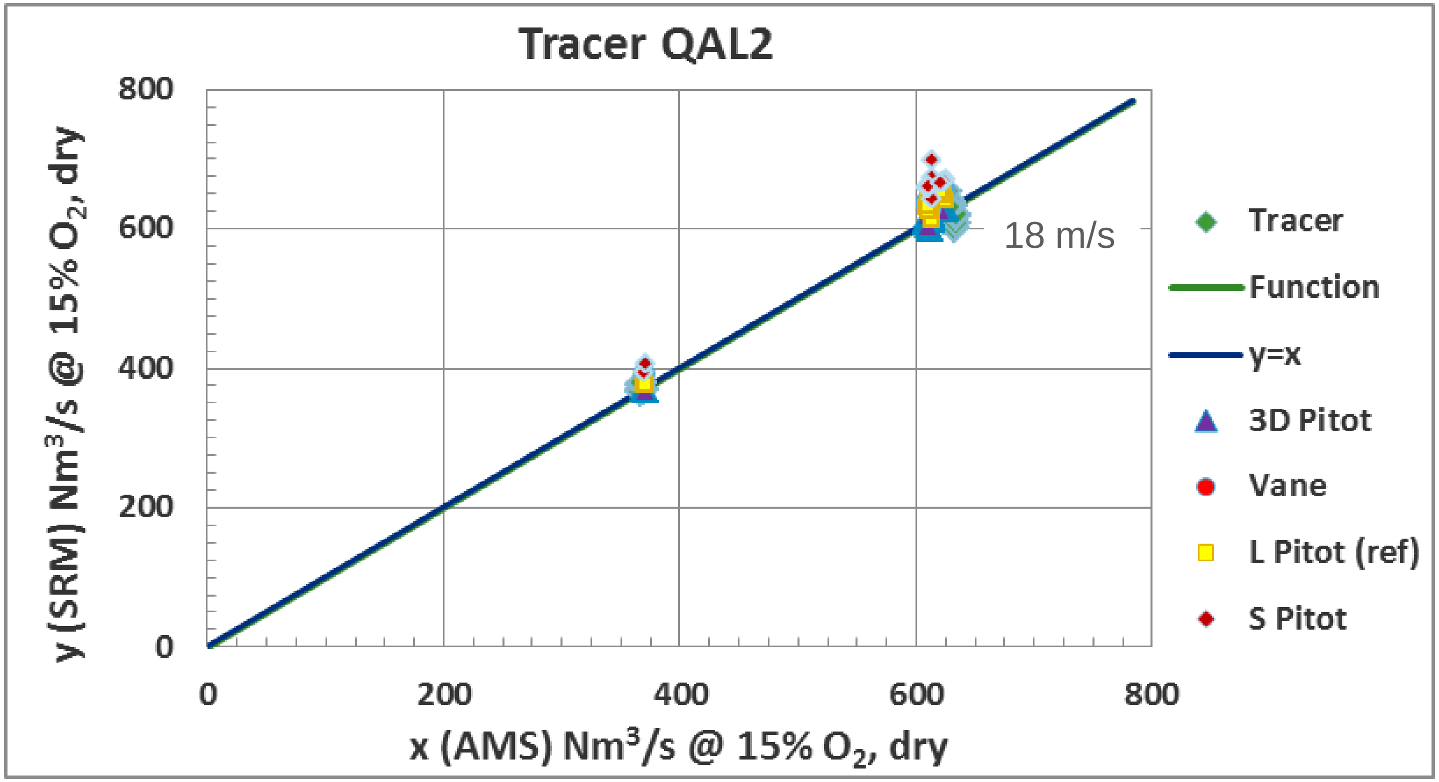
3. $R^2 > 0.9$

Field trial 1: Combined Cycle Gas Turbine (CCGT)

7.0m diameter

Field trial 1 (CCGT): Preliminary results

	$\underline{V}_{god}$	Nm^3/s		15 vol % O_2 Dry, 0°C, 101.325kPa					
	no. Meas	Slope	Max	|D|	limit |D|	sD	Max sD	R^2	Limit R^2
Ref. L-Pitot	14	1.034	653.1	19.96	36.69	11.27	30.56	0.986	0.90
3D Pitot	15	1.005	629.6	2.68	32.85	5.78	29.51	0.996	0.90
S-Pitot	15	1.078	695.4	45.39	39.61	13.69	32.58	0.979	0.90
Vane anemometer	14	1.042	652.1	24.15	33.38	4.42	30.51	0.998	0.90
Tracer Gas	20	0.998	652.8	0.95	36.62	13.66	30.78	0.986	0.90

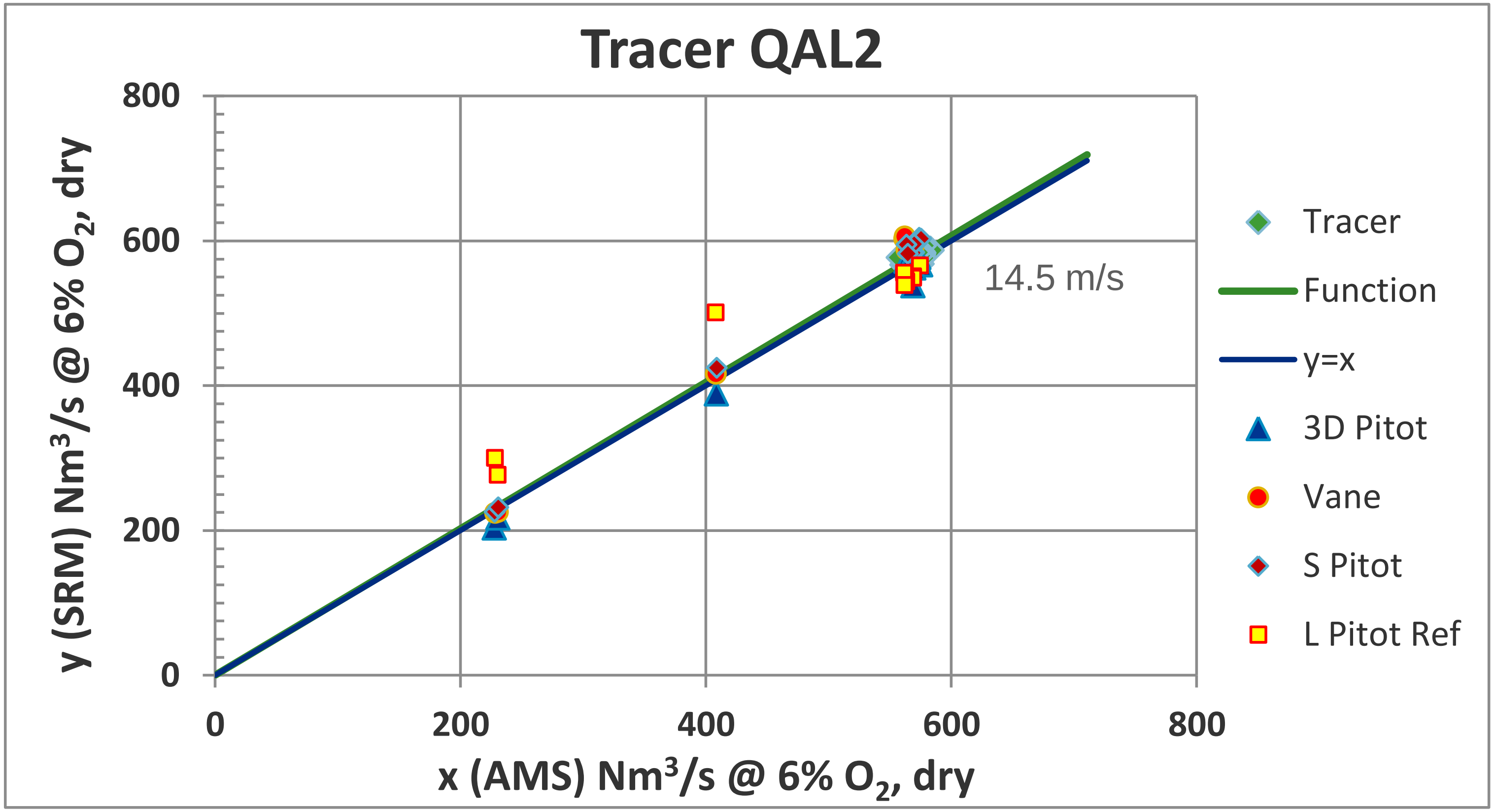


Field trial 2: Coal fired Power Plant (wet stack)

8.0m diameter

Field trial 2 (Coal fired PP): Preliminary Results

	$\underline{V}_{god}$	Nm^3/s		6 vol % O_2 Dry, STP		From Plant calc.			
	no. Meas	Slope	Max	|D|	limit |D|	sD	Max sD	R^2	Limit R^2
Ref. L-Pitot	10	1.040	565.8	19.14	53.14	44.820	25.501	0.832	0.90
3D Pitot	11	1.000	577.2	0.22	33.63	10.844	26.795	0.994	0.90
S-Pitot	11	1.057	604.0	27.36	33.67	8.565	28.010	0.997	0.90
Vane anemometer	9	1.066	606.0	30.77	39.37	16.584	27.894	0.990	0.90
Tracer Gas	19	1.021	592.5	11.74	31.56	7.837	27.917	SP<15%	0.90



Field trial summary

Provide guidance on the choice of stack testing methods for use at coal and gas fired power plant

- [The standard AST Validity Test and the QAL2 Variability Test are suitable for verifying stack flow calculations]
- Pitot measurements can be made on wet stacks although frequent purging of the impulse lines is required
- 3D Pitot and tracer methods give results that are closest to the calculated stack flow but all methods, including vane anemometers, are acceptable (at low swirl)
- Tracer dilution methods are rapid, can measure the dry stack flow rate directly (for comparison with calculated flow) and do not require the stack diameter/cross-sectional area. However, tracer gas cylinders and a suitable tracer injection point are required.

Other Quality Assurance Aspects – QAL1

Define a common approach to the implementation, and Quality Assurance, of stack flow rate calculations

Quality Assurance Level 1 - Gaseous and Liquid Fuels

- Fiscal level metering is assumed in EN ISO 16911 for gas and liquid fuels (±1.5% based on the Tier 4 EU ETS). The stack flow uncertainty targets are then 2% for natural gas (with local CV measurement) and 3% for oil firing (Note that EU ETS requires ± 2.5% for total CO_2 mass emission).
- Uncertainty assessment is performed for EU ETS and calibration certificates are available. This level of QA should apply to new fuel meters.
- Existing Unit level metering may not be to fiscal quality. In this situation, the meter should be acceptable provided that the QAL2/AST are passed (cf EN14181 Annex H).

Other Quality Assurance Aspects – QAL1

Solid Fuels

- Power (or Thermal Output) / Efficiency → Thermal input
- Electricity (or steam flow metering) are to fiscal quality and plant efficiency is well characterised (in the normal operating and reporting range)
- Fuel factor uncertainty depends on the fuel, e.g., ± 2% for hard coal and biomass pellets
- Total uncertainty for hard coal ≤ ± 5% with a maximum target uncertainty for variable solid fuel ≤ ± 7.5%
- For new plant, QAL1 is the initial calibration of key instruments and the guarantee performance test
- For existing plant, it should be acceptable to pass the QAL2/AST (cf EN14181 Annex H)

Other Quality Assurance Aspects – QAL3

Quality Assurance Level 3 - Gaseous and Liquid Fuels

- For fiscal level metering and CV measurement, regular meter/instrument inspection and calibration satisfies the QAL3 requirement (routine for EU ETS). This level of QA should apply to new fuel meters.
- Existing Unit level metering may not be to fiscal quality. In this situation, the meter should be acceptable provided that the QAL2/AST is passed and the meter is within calibration date.
- Periodic checks against billing or plant performance data can provide additional confidence in the ongoing quality of the measurement.

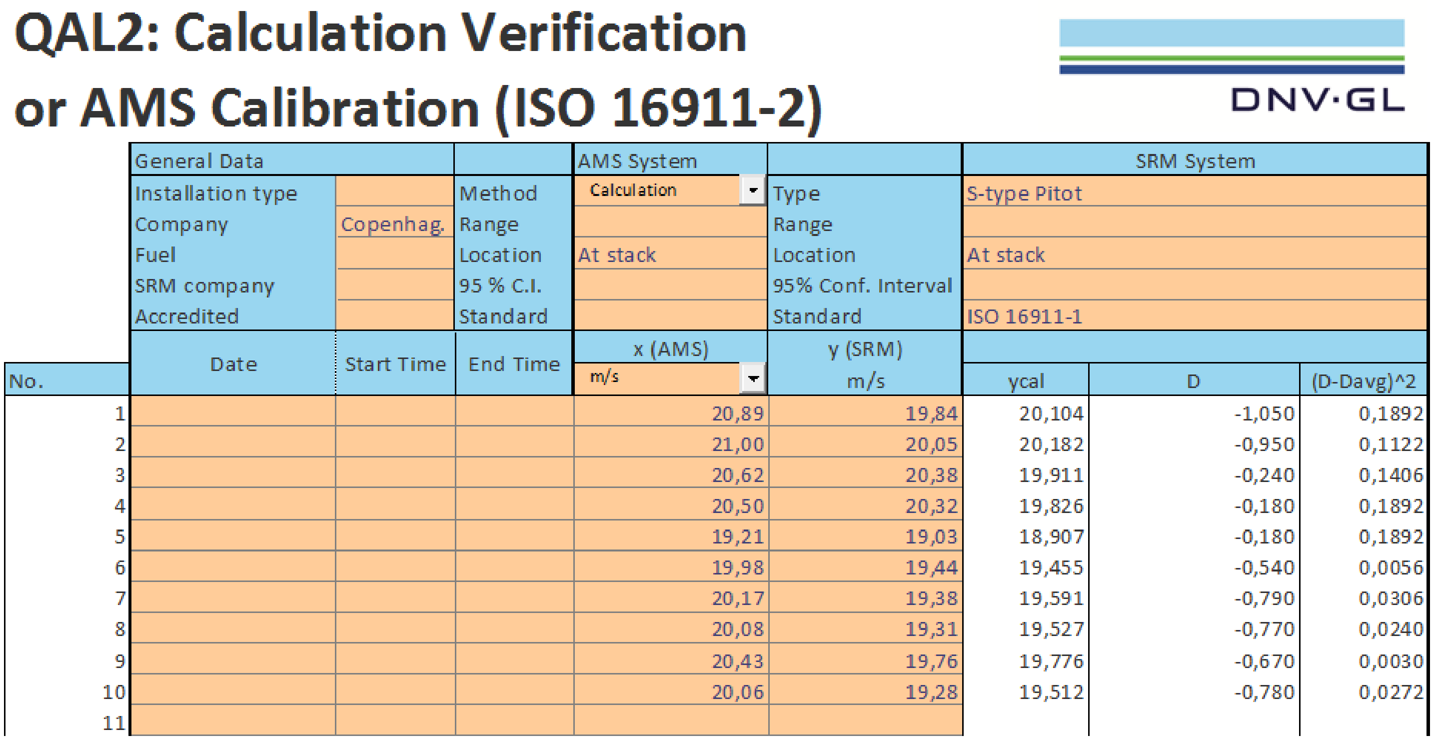
Other Quality Assurance Aspects – QAL3

Solid Fuels

- Calibration to the manufacturer's specification of key instruments (electricity or steam metering)
- Periodic checks against billing or plant performance data can provide additional confidence in the ongoing quality of the measurement.

Implementing Quality Assurance requirements

Provide a tool for applying QA requirements to stack gas flow rate calculation in compliance with the appropriate standards (EN ISO 16911 and EN 14181)



QAL2: Calculation Verification
or AMS Calibration (ISO 16911-2)

DNV·GL

General Data			AMS System		SRM System
Installation type		Method	Calculation	Type	S-type Pitot
Company	Copenhag.	Range		Range	
Fuel		Location	At stack	Location	At stack
SRM company		95 % C.I.		95% Conf. Interval	
Accredited		Standard		Standard	ISO 16911-1

No.	Date	Start Time	End Time	x (AMS) m/s	y (SRM) m/s	ycal	D	(D-Davg)^2
1				20,89	19,84	20,104	-1,050	0,1892
2				21,00	20,05	20,182	-0,950	0,1122
3				20,62	20,38	19,911	-0,240	0,1406
4				20,50	20,32	19,826	-0,180	0,1892
5				19,21	19,03	18,907	-0,180	0,1892
6				19,98	19,44	19,455	-0,540	0,0056
7				20,17	19,38	19,591	-0,790	0,0306
8				20,08	19,31	19,527	-0,770	0,0240
9				20,43	19,76	19,776	-0,670	0,0030
10				20,06	19,28	19,512	-0,780	0,0272
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Conclusions

- VGB Research Project makes recommendations with regards to the QA of continuous flow monitoring calculations
- SRM applicability for coal & gas fired power plant (Excel tool)
- Initial Verification by applying the QAL2 Variability Test and the AST Validity Test (demonstrated at two plant)
- For Gaseous and Liquid Fuels:
  - QAL1 based on EU ETS calibrations, where applicable
  - Otherwise based on passing QAL2/AST verification
  - QAL3 based on fuel meter calibration, AST and plant performance checks
- For Solid Fuels:
  - QAL1 is the calibration of electricity/steam flow and the guarantee performance test
  - QAL3 based on instrument calibration, AST and plant performance checks