METERPROOF

DP Flowmeter Uncertainty Analysis · ISO 5168:2005 / ISO 5167-1:2022 · Methodology v7.0

RPT-2026-000023
2026-03-23 00:52 UTC
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DOES NOT COMPLY (FLOW-WEIGHTED)

Design-point U = ±0.68% is within the limit, but flow-weighted U = ±2.35% across 365 days exceeds the EU ETS MRR — Tier 4 limit of ±1.5%.

FRAMEWORK	LIMIT	DESIGN-POINT U	FLOW-WEIGHTED U (365D)
EU ETS MRR — Tier 4	≤ ±1.5%	±0.68%	±2.35%

EXPANDED UNCERTAINTY U (K=2.000) — % OF READING

0.68%

DOES NOT COMPLY (FLOW-WEIGHTED) TYPE A + B

u_c = ±0.338% | U = ±0.677% (k=2.000, Fixed k=2)

q ≈ 689.80 kg/h → absolute: ±4.67 kg/h

C_d = 0.60034 | Re = 1.32e+05 | ε = 0.99590 | β = 0.3528

⚠ SYSTEMATIC MEASUREMENT BIAS DETECTED

This is separate from uncertainty — the meter is consistently reading under by a fixed amount

LAB MEAN DENSITY		FLOW COMPUTER DENSITY		FLOW BIAS
5.247 kg/m³	≠	4.880 kg/m³	→	UNDER 3.76%
n = 12 samples		design-basis assumed value		UNDER-READING

What this means:

The meter is estimated to UNDER-read mass flow by approximately 3.76% (25.91 kg/h at design flow). Sensitivity c(ρ)=0.5 means a 1% density error produces approximately 0.5% flow error. This is a systematic bias, not an uncertainty — the meter is consistently reading low by this amount.

⚠ ACTION REQUIRED: Update the flow computer density value or install live density compensation to eliminate this systematic error. A 25.91 kg/h bias at design flow may have significant fiscal or compliance implications.

Note: Bias and uncertainty are independent. A meter can comply with its uncertainty requirement while having a significant systematic bias. Uncertainty quantifies scatter; bias quantifies offset. Both must be addressed for accurate measurement.
Compensation: Live P / Live T / Fixed ρ

AUDIT IDENTIFICATION

Site / Plant	A Platform
Meter Tag	FT1001
Service	Fuel Gas
Prepared By	Joe Bloggs
Document Ref.	—
Framework	EU ETS MRR — Tier 4 — Reg. (EU) 2018/2066 Annex II
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Β RATIO	REYNOLDS NO.	DOMINANT SOURCE
0.3528	1.32e+05	Discharge coefficient Cd

UNCERTAINTY BUDGET — ISO 5168:2005 / GUM (ISO/IEC GUIDE 98-3)

B = Type B (ν=∞) · A = Type A (statistical, ν=n−1)

QUANTITY	TYPE	SOURCE	C_i	$U(X_i)$ %	$C_i \cdot U$ %	N_i	% VARIANCE
Discharge coefficient Cd B	B	ISO 5167 formula	1.000	0.2550	0.2550	∞	56.8%
ΔP transmitter — Type B B	B	Datasheet + envir. effects	0.500	0.3371	0.1686	∞	24.8%
Fluid density ρ — Type B B	B	Direct input	0.500	0.2500	0.1250	∞	13.6%
Fluid density ρ — Type A (n=12) A	A	Periodic lab samples	0.500	0.0977	0.0488	11	2.1%
Combined standard uncertainty $u_c(q)$					**0.3384%**	**∞**	
Expanded uncertainty U = k·u_c, k=2.000 (Fixed k=2)					**0.6768%**		

QUANTITY	TYPE	SOURCE	C_i	$U(X_i)$ %	$C_i \cdot U$ %	N_i	% VARIANCE
Element bore d B	B	Dimensional inspection	2.063	0.0181	0.0372	∞	1.2%
Signal chain / DAQ B	B	Flow computer, ADC, totaliser	1.000	0.0312	0.0312	∞	0.9%
Viscosity μ (via Re → Cd) B	B	Fluid analysis	0.018	1.5000	0.0270	∞	0.6%
Expansibility factor ε B	B	ISO 5167-1 formula (κ + τ)	1.000	0.0017	0.0017	∞	0.0%
Pipe bore D B	B	Pipe specification	0.063	0.0245	0.0015	∞	0.0%
Combined standard uncertainty $u_c(q)$					**0.3384%**	**∞**	
Expanded uncertainty $U = k \cdot u_c$, k=2.000 (Fixed k=2)					**0.6768%**		

INPUT SUMMARY

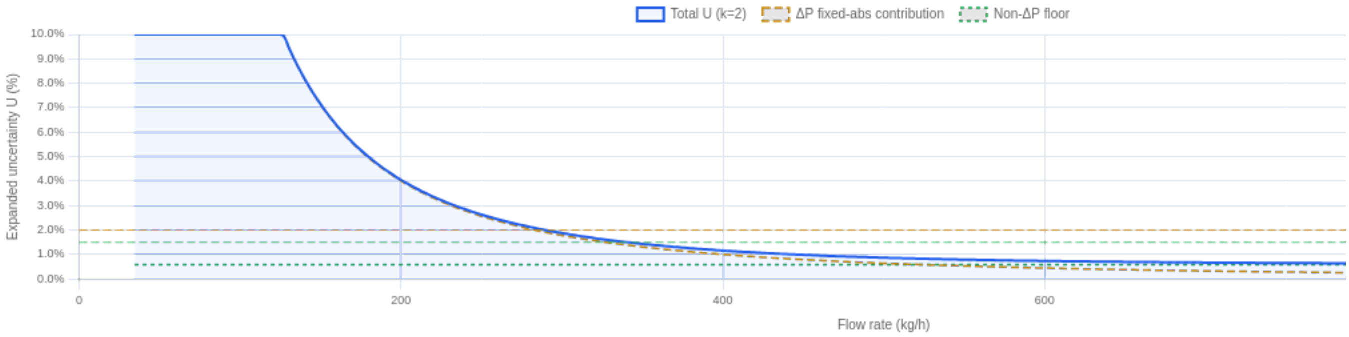
Primary element	Orifice Plate (ISO 5167-2)
Pipe bore D	102.032 mm ± 0.050 mm (k=2)
β = d/D	0.35283
ΔP: URL / Span / Op.	621 / 150 / 100 mbar
Line pressure	6.2 bara
Flow compensation	Live P / Live T / Fixed ρ
Line density	4.8800 kg/m³ ± 0.50% (k=2 Type B)
Tap configuration	Flange taps (1" / 1")
Element bore d	36.000 mm ± 0.013 mm (k=2)
Cd source	ISO 5167 formula
Operating % span / URL	66.7% / 16.1%
Line temperature	17 °C
Fluid	Gas — Direct ρ
Estimated flow	≈ 689.80 kg/h

FINDINGS & RECOMMENDATIONS

- ✓ U = ±0.68%: compliant with EU ETS MRR — Tier 4 (45% of allowed limit).
- Dominant contributor: Discharge coefficient Cd — 57% of combined variance.
- Second largest: ΔP transmitter — Type B — 25%.
- ΔP at 66.7% of span. Good operating point (50–90%).
- Re ≈ 1.32e+5: ✓ Turbulent — Cd valid
- Line pressure effect included: 0.012% of reading — minor contributor.
- Ambient temperature effect included: 0.130% of reading — within normal range.
- Flow bias estimate: Lab density data (n=12) suggests the meter under-reads by ~3.76% (mass output). See flow bias panel above for detail. Consider correcting the design-basis density or updating the flow computer configuration.
- Coverage factor k = 2.000 → ≈95.45% confidence (Fixed k=2). ISO 5168 Clause 6.2.

UNCERTAINTY ACROSS THE MEASUREMENT RANGE

ΔP ∝ q², so at 50% of design flow the DP is only 25% of design DP. Fixed absolute DP errors (% URL, % span) amplify as turndown increases. Dimensional, Cd, and density uncertainties are constant % of reading and set the floor. The dashed threshold line corresponds to the selected compliance framework limit.



METHODOLOGY REFERENCE

Uncertainty evaluated per **ISO 5168:2005**, cross-referenced by ISO 5167-1:2022 Clause 8. Type A and Type B evaluation per GUM (ISO/IEC Guide 98-3). Welch-Satterthwaite effective degrees of freedom applied when Type A contributions present (GUM G.4).

$$q = C_d \cdot \varepsilon \cdot (\pi/4) \cdot d^2 \cdot \sqrt{2\Delta P/\rho} / \sqrt{1-\beta^4}$$

$$u_c(q)/q = \sqrt{\Sigma[c_i \cdot u(x_i)/x_i]^2} \quad U = k \cdot u_c(q) \quad \nu_{eff} = u_c^4 / \Sigma[(c_i \cdot u_i)^4/\nu_i]$$

Prepared by:	Reviewed by:	Date:
Joe Bloggs		2026-03-23

APPENDIX A — STEP-BY-STEP CALCULATION WORKINGS

Each uncertainty budget row is derived below showing the raw input, unit conversion, standard uncertainty, sensitivity coefficient, and final contribution. References to ISO 5167 / ISO 5168 / GUM clauses are cited for each step.

Discharge coefficient Cd B

Source	ISO 5167 formula
Components	RSS of: ISO formula/cal uncertainty + additional systematic + flow profile
Standard uncertainty (k=1)	u(Cd) = 0.2550%
Sensitivity coefficient	c(Cd) = 1.000 (direct proportionality)
Reference	ISO 5167-1:2022 Clause 8; ISO 5168:2005 Table 1
Contribution	c(Cd) × u(Cd) = 1.000 × 0.2550 = 0.2550%

ΔP transmitter — Type B B

Source	Transmitter datasheet: accuracy, drift, line pressure, calibration
Method	Each DP error term converted from % URL/span/rdg → % of reading at operating ΔP
Conversion	% URL → % rdg: multiply by URL/ΔP_op; % span → % rdg: multiply by span/ΔP_op
Combined (RSS)	u(ΔP) = √Σ[term²] = 0.3371% of reading (k=1)
Sensitivity coefficient	c(ΔP) = 0.500 (flow ∝ √ΔP, so ∂q/∂ΔP × ΔP/q = 0.5)
Reference	ISO 5168:2005 Clause 5.4; ISO 5167-1:2022 Clause 8
Contribution	c(ΔP) × u(ΔP) = 0.500 × 0.3371 = 0.1686%

Fluid density ρ — Type B B

Source	Direct input
Standard uncertainty (k=1)	u(ρ) = 0.2500%
Includes	Design-basis uncertainty + compensation effects (if applicable)
Sensitivity coefficient	c(ρ) = 0.500 (flow ∝ 1/√ρ, so ∂q/∂ρ × ρ/q = −0.5)
Reference	ISO 5167-1:2022 Clause 8; ISO 5168:2005 Table 1
Contribution	c(ρ) × u(ρ) = 0.500 × 0.2500 = 0.1250%

Fluid density ρ — Type A (n=12) A

Source	Periodic lab samples
Method	Type A: u_A = s/(x̄√n) from lab sample data
Standard uncertainty (k=1)	u_A(ρ) = 0.0977%
Sensitivity coefficient	c(ρ) = 0.500
Degrees of freedom	ν = n−1 = 11
Reference	ISO 5168:2005 Clause 5.2; GUM 4.2
Contribution	0.500 × 0.0977 = 0.0488%

Element bore d B

Raw input	d uncertainty from dimensional inspection certificate
Standard uncertainty (k=1)	u(d) = 0.0181% (input ÷ 2 if k=2 datasheet)
Sensitivity coefficient	c(d) = 2 + 4β⁴/(1−β⁴) = 2 + 4×0.0157 = 2.063
Reference	ISO 5167-1:2022 Clause 8, Eq. for ∂q/∂d
Contribution	c(d) × u(d) = 2.063 × 0.0181 = 0.0372%

Signal chain / DAQ B

Source	Flow computer, ADC, totaliser
Components	RSS of: flow computer resolution + ADC linearity + totaliser + thermal expansion
Standard uncertainty (k=1)	u(signal) = 0.0312%
Sensitivity coefficient	c = 1.000 (direct addition to flow uncertainty)
Reference	ISO 5168:2005 Clause 5.4
Contribution	1.000 × 0.0312 = 0.0312%

Viscosity μ (via Re → Cd) B

Source	Fluid analysis
Standard uncertainty (k=1)	$u(\mu) = 1.5000\%$
Sensitivity coefficient	$c(\mu) = 0.018$ (second-order: Re→Cd dependence)
Reference	ISO 5168:2005; sensitivity via iterative Cd(Re) dependence
Contribution	$0.018 \times 1.5000 = 0.0270\%$

Expansibility factor ε B

Source	ISO 5167-1 formula (κ + τ)
Method	Combined from κ uncertainty and $\tau = \Delta P/P_1$ propagation paths
Standard uncertainty (k=1)	$u(\varepsilon) = 0.0017\%$
Sensitivity coefficient	$c(\varepsilon) = 1.000$
Reference	ISO 5167-1:2022 Eq.5 (expansibility formula)
Contribution	$1.000 \times 0.0017 = 0.0017\%$

Pipe bore D B

Raw input	D uncertainty from pipe specification or measurement
Standard uncertainty (k=1)	$u(D) = 0.0245\%$
Sensitivity coefficient	$c(D) = 4\beta^4/(1-\beta^4) = 4\times0.0157 = 0.063$
Reference	ISO 5167-1:2022 Clause 8, Eq. for ∂q/∂D
Contribution	$c(D) \times u(D) = 0.063 \times 0.0245 = 0.0015\%$

Combined Standard Uncertainty RSS

Formula	$u_c(q)/q = \sqrt{\Sigma[c_i \cdot u(x_i)/x_i]^2}$
Reference	ISO 5168:2005 Clause 7.3; GUM Eq.10
Calculation	$u_c = \sqrt{(0.2550^2 + 0.1686^2 + 0.1250^2 + 0.0488^2 + 0.0372^2 + ...)}$
Result	$u_c(q) = 0.3384\%$

Expanded Uncertainty Final

Formula	$U = k \times u_c(q)$
Coverage factor	k = 2.000 (Fixed k=2)
Effective DoF	$\nu_{eff} = \infty$
Reference	ISO 5168:2005 Clause 6.2; GUM G.4 (Welch-Satterthwaite)
Result	$U(q) = 2.000 \times 0.3384 = 0.6768\%$

APPENDIX B — COMPLETE USER INPUT DATA

All user-supplied input values exactly as entered into the calculator. These values determine the calculation result and should be verified by the reviewing engineer.

STEP 1 — PRIMARY ELEMENT & IDENTIFICATION

Primary element type	Orifice Plate (ISO 5167-2)
Tap configuration	flange
Fluid phase	Gas
Calibration status	Uncalibrated (ISO 5167 formula)
Compliance framework	EU ETS MRR — Tier 4 — Reg. (EU) 2018/2066 Annex II
Framework uncertainty limit	≤ ±1.5% (k=2)

STEP 2 — GEOMETRY

Pipe bore D	102.032 mm ± 0.05 mm (k=2)
Element bore d	36 mm ± 0.013 mm (k=2)

STEP 3 — DP TRANSMITTER

DP upper range limit (URL)	621 mbar
DP calibrated span	150 mbar
Operating ΔP	100 mbar
Accuracy	0.65% (reading)
Drift / stability	0.01% (url)
Line pressure effect (ΔP)	0.05% (span)
Calibration uncertainty	0.05% (span)

STEP 3 — PROCESS CONDITIONS

Line static pressure	6.2 bara
Pressure uncertainty	0.10% (k=2)
Line temperature	17 °C
Temperature uncertainty	1.0 K (k=2)

STEP 3 — DENSITY

Gas density input mode	direct
Gas density at line	4.88 kgm3
Gas density uncertainty	0.5% (k=2)
Isentropic exponent κ	1.400 ± 0.5% (k=2)
Dynamic viscosity	0.0000181 Pas ± 3.0% (k=2)

STEP 3 — COMPENSATION

Pressure compensation	live
Temperature compensation	live
Density compensation	fixed

STEP 5 — CD & INSTALLATION

Additional Cd systematic error	EXCLUDED
Flow profile / swirl distortion	0.1%

STEP 5 — SIGNAL CHAIN

Flow computer resolution	0.01%
4–20 mA / ADC linearity	EXCLUDED
Totaliser / integration error	0.05%
Thermal expansion correction	0.03%

STEP 5 — REPORTING

Coverage factor k	2
Flow output unit	kgh

EXCLUDED INPUTS

The following inputs were explicitly excluded from the calculation by the user with documented justification.

PARAMETER	ORIGINAL VALUE	REASON FOR EXCLUSION
Additional Cd Systematic Error (%)	~~0.0%~~	*Recent inspection showed no sign of wear*
4–20 mA / ADC Linearity (%)	~~0.02%~~	*Modbus comms rather than 4-20*

APPENDIX C — INSTRUMENT & DOCUMENT REGISTER

Instrument identification, calibration certificates, and maintenance references for audit traceability. This information does not affect the uncertainty calculation.

ΔP TRANSMITTER

Make / Model	Rosemount 3051S
Serial Number	SN-12345
Calibration Cert. No.	CC-01234
PM / Work Order No.	PM-1234

PRESSURE TRANSMITTER

Make / Model	Rosemount 3051TG
Serial Number	SN-12346
Calibration Cert. No.	CC-01235
PM / Work Order No.	PM-1235

TEMPERATURE TRANSMITTER

Make / Model	Rosemount 3144P
Serial Number	SN-12347
Calibration Cert. No.	CC-01236
PM / Work Order No.	PM-1236

DENSITOMETER

Make / Model	NA
Serial Number	SN-12349

ORIFICE PLATE / PRIMARY ELEMENT

Manufacturer	Daniel
Serial / ID No.	SN-12348
Dimensional Inspection Cert.	CC-01237

FLOW COMPUTER

Make / Model	ROC800
Serial Number	SN-12349
Software Version	V3.2.1
PM / Verification No.	PM-1238

LABORATORY / SAMPLING

Lab Name / Accreditation	Intertek
Analysis Method	ISO6976
Sampler / GC Serial	SN-12341

APPENDIX D — ANNUAL FLOW PROFILE UNCERTAINTY BACK-TEST

The design-point uncertainty represents the meter at a single operating flow. In practice, flow varies throughout the year. This appendix back-tests the expanded uncertainty at each day's average flow rate using the turndown curve from the main analysis, giving a flow-weighted mean uncertainty — the true operational uncertainty across the meter's actual operating range.

FRAMEWORK LIMIT EXCEEDED ON 248 DAYS

Flow-weighted mean uncertainty: ±2.356% across 365 days of flow data

FLOW-WEIGHTED U	FRAMEWORK LIMIT	DAYS EXCEEDING
±2.356%	≤ ±1.5%	248 / 365

DATA POINTS	FLOW-WEIGHTED U	SIMPLE MEAN U	MIN U	MAX U
365 days	±2.356%	±3.898%	±0.905%	±15.0%

STATISTIC	VALUE	INTERPRETATION
Flow-weighted mean U	±2.356%	Best estimate of the meter's true operational uncertainty — weights high-flow (low-U) days proportionally
Simple arithmetic mean U	±3.898%	Equal weight to all days — may overstate if many low-flow days
P10 / P50 / P90 / P95	0.905 / 2.509 / 11.716 / 15.0%	Percentiles of the daily uncertainty distribution
Worst day	±15.0% at q ≈ 38	Design fraction: 6.0% — lowest flow day with highest uncertainty
Days above limit	248 / 365 (67.9%)	Days where U exceeded the 1.5% framework limit

UNCERTAINTY DISTRIBUTION

U RANGE (%)	DAYS	%	DISTRIBUTION
0.0–1.31	117	32.1%	
1.31–2.62	172	47.1%	
7.88–9.19	28	7.7%	
10.5–11.81	16	4.4%	
14.44–15.75	32	8.8%	

Method: For each day's average flow rate q_i, the design-point ΔP is scaled as $\Delta P_i = \Delta P_{design} \times (q_i/q_{design})^2$. Fixed absolute DP errors (% URL, % span) are re-evaluated at ΔP_i, amplifying at low flow. Non-DP contributors (Cd, dimensions, density, signal chain) remain constant % of reading. The expanded uncertainty $U_i = k \times \sqrt{(u_{DP,i}^2 + u_{other}^2)}$ is computed for each day.

Flow-weighted mean: $\bar{U} = \Sigma(U_i \times q_i) / \Sigma q_i$ — weights each day by its volumetric/mass contribution to the annual total. This is the most representative single-number uncertainty for annual totals used in EU ETS MRR and fiscal reporting.

Input data: 365 daily avg values in m3h. Design flow: 689.8 kg/h.