

# DP Flowmeter Uncertainty Analysis Report

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## Uncertainty Analysis Report

Expanded uncertainty per ISO 5168:2005, with sensitivity coefficients from ISO 5167 and Type A/B separation per GUM (ISO/IEC Guide 98-3). Welch-Satterthwaite effective degrees of freedom applied when Type A data is present.



**COMPLIANT**

U = ±1.16% is within the EU ETS MRR – Tier 4 limit of ±1.5%.

FRAMEWORK	LIMIT	RESULT
EU ETS MRR – Tier 4	≤ ±1.5%	±1.16%

EXPANDED UNCERTAINTY U (K=2.120) – % OF READING

**1.16%**

COMPLIANT    TYPE A + B    v\_eff=18

Standard  $u_c = \pm 0.548\%$  | Expanded U = ±1.162% (k=2.120, W-S (v\_eff=18))  
At  $q \approx 786.55$  kg/h → absolute: ±9.14 kg/h  
Iterated Cd = 0.60113 | Re\_D = 1.506e+5 |  $\epsilon = 0.99466$

**Type A contributions included:** Density  $u_A = \pm 0.8667\%$  (k=1) from n=8 lab samples. Welch-Satterthwaite v\_eff=18, effective k=2.120.



### ESTIMATED FLOW BIAS FROM LAB DENSITY DATA

Lab samples (n=8) indicate the actual fluid density differs from the flow computer's assumed value. This produces a systematic bias in the reported flow.

LAB MEAN $\rho$	DESIGN $\rho$	$\rho$ DEVIATION	FLOW BIAS
4.986 kg/m <sup>3</sup>	4.880 kg/m <sup>3</sup>	+2.177%	UNDER 1.09%

The meter is estimated to UNDER-read mass flow (kg/h) by ~1.09% ( $\approx -8.56$  kg/h at design flow).

Actual fluid is denser than the flow computer assumes  $\rightarrow$  it under-multiplies when converting to mass  $\rightarrow$  reported mass flow is low.

P and T are compensated but density is fixed — bias is from the assumed  $\rho$  not tracking actual fluid conditions.

Consider adding EOS-based density correction or an online densitometer.

Note: this is a point estimate from lab data, not a calibration. The flow bias sensitivity coefficient  $c(\rho)=0.5$  means a 1% density error produces  $\sim 0.5\%$  flow error.

#### AUDIT IDENTIFICATION

Site / Plant	North Sea	Meter tag	FT2010
Service	Fuel Gas	Prepared by	A N Other
Document ref.	—	Compliance framework	EU ETS MRR – Tier 4 – Reg. (EU) 2018/2066 Annex II
Calculation date	2026-03-18 15:10	Input fingerprint	E04A24A3

B RATIO	REYNOLDS NO.	DOMINANT SOURCE
0.3528	1.51e+5	Fluid density $\rho$ – Type A (n=8)

**Uncertainty Budget – ISO 5168:2005 / GUM (ISO/IEC Guide 98-3)**

**B** = Type B ( $v=\infty$ )    **A** = Type A (statistical,  $v=n-1$ )

QUANTITY	SOURCE	SENS. COEFF. $C_U$	STD. UNC. $U(X)$ % (K=1)	CONTRIBUTION $C_U U(X)$ %	DOF $N_U$	% VARIANCE
Fluid density $\rho$ – Type A (n=8) <b>A</b>	Periodic lab samples	0.500	0.8667	0.4334	7	62.5%
Discharge coefficient $C_d$ <b>B</b>	ISO 5167 formula	1.000	0.2550	0.2550	$\infty$	21.6%
$\Delta P$ transmitter – Type B <b>B</b>	Datasheet + envir. effects	0.500	0.3392	0.1696	$\infty$	9.6%
Fluid density $\rho$ – Type B <b>B</b>	Direct input	0.500	0.2500	0.1250	$\infty$	5.2%
Element bore $d$ <b>B</b>	Dimensional inspection	2.063	0.0181	0.0372	$\infty$	0.5%
Signal chain / DAQ <b>B</b>	Flow computer, ADC, totaliser	1.000	0.0312	0.0312	$\infty$	0.3%
Viscosity $\mu$ (via $Re \rightarrow C_d$ ) <b>B</b>	Fluid analysis	0.018	1.5000	0.0270	$\infty$	0.2%
Expansibility factor $\varepsilon$ <b>B</b>	ISO 5167-1 formula ( $\kappa + \tau$ )	1.000	0.0023	0.0023	$\infty$	0.0%
Pipe bore $D$ <b>B</b>	Pipe specification	0.063	0.0245	0.0015	$\infty$	0.0%
<b>Combined standard uncertainty <math>u_c(q)</math> [ISO 5168 Eq.7]</b>					<b>18</b>	<b>0.5480%</b>
<b>Expanded uncertainty <math>U = k \cdot u_c(q)</math>, <math>k=2.120</math> (W-S (<math>v_{eff}=18</math>)) [ISO 5168 Eq.9]</b>						<b>1.1617%</b>

### Input Summary

Primary element	Orifice Plate (ISO 5167-2)	$\Delta P$ : URL / Span / Op.	621 / 250 / 130 mbar
Tap configuration	Corner taps	Operating % span / URL	52.0% / 20.9%
Pipe bore D	102.030 mm $\pm$ 0.050 mm (k=2)	Line pressure	6.2 bara
Element bore d	36.000 mm $\pm$ 0.013 mm (k=2)	Line temperature	17 °C
$\beta = d/D$	0.35284	Flow compensation	COMPLIANT
Cd source	ISO 5167 formula (uncalibrated)	Fluid	Gas – Direct $\rho$
		Line density	4.8800 kg/m <sup>3</sup> $\pm$ 0.50% (k=2 Type B)
		Field data entry basis	Line density (direct)
		Estimated flow	$\approx$ 786.55 kg/h

### Findings & Recommendations

✓  $U = \pm 1.16\%$ : compliant with EU ETS MRR – Tier 4 (77% of allowed limit).

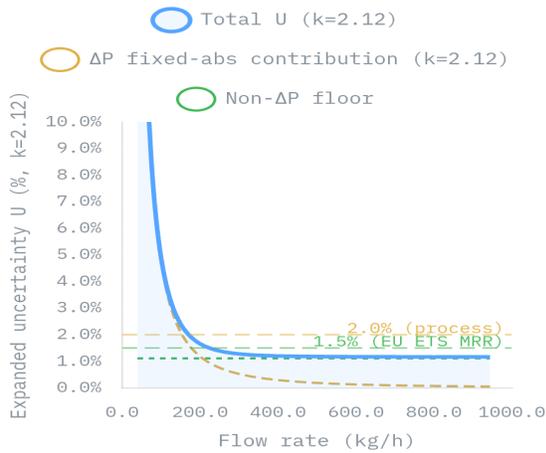
- Dominant contributor: Fluid density  $\rho$  – Type A (n=8) – 63% of combined variance.
- Second largest: Discharge coefficient  $C_d$  – 22%.
- $\Delta P$  at 52.0% of span. Good operating point (50–90%).
- $Re \approx 1.51e+5$ : ✓ Turbulent –  $C_d$  valid
- Type A density  $u_A=0.867\%$  exceeds design-basis Type B  $u_B=0.250\%$ . Real fluid variability is larger than datasheet estimate.
- Line pressure effect included: 0.009% of reading – minor contributor.
- Ambient temperature effect included: 0.130% of reading – within normal range.
- **Flow bias estimate:** Lab density data (n=8) suggests the meter under-reads by  $\sim 1.09\%$  (mass output). See flow bias panel above for detail. **Consider correcting the design-basis density or updating the flow computer configuration.**
- Welch-Satterthwaite effective DoF  $v_{eff} = 18$ . Coverage factor  $k = 2.120$  (W-S ( $v_{eff}=18$ )).
- Coverage factor  $k = 2.120 \rightarrow \approx 95\%$  confidence (W-S ( $v_{eff}=18$ )). ISO 5168 Clause 6.2.

## Uncertainty Across the Measurement Range

**Why uncertainty rises at low flow:**  $\Delta P \propto q^2$ , so at 50% of design flow the DP is only 25% of design DP. Fixed absolute DP errors (% URL, % span) therefore amplify as turndown increases – their contribution to flow uncertainty  $\propto 1/q^2$ . Dimensional, Cd, and density uncertainties are constant % of reading and set the floor. The chart shows where these meet and defines the *effective lower range limit* for a given uncertainty target. The dashed threshold line corresponds to the selected compliance framework limit.

Max flow: 786.55 kg/h (design) Min flow (U≤1.5%): 224.00 kg/h

Min flow (U≤2%): 171.24 kg/h Turndown (1.5%): 3.5:1



All terms held at design-point values; only  $\Delta P$  uncertainty varies with flow ( $DP = DP_{\text{design}} \times (q/q_{\text{design}})^2$ ). Environmental effects and Type A density treated as constant % of reading.

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