EURAMET TC Project
Final Report

Project Title

Pilot study on high-pressure natural gas primary calibration facilities

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Menne Schakel (VSL), Netherlands

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Intercomparison of primary high-pressure natural gas flow standards

Final report

Coordinator	VSL B.V., Delft, The Netherlands
Participating partner	FORCE Technology, Vejen, Denmark
Third party	PTB, Braunschweig, Germany

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Contents

Intercomparison of primary high-pressure natural gas flow standards

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Summary

An intercomparison of primary high-pressure natural gas flow standards was performed. Participating laboratories were VSL and FORCE, while PTB agreed to take the role of the independent third party. Both VSL and FORCE use a piston prover as primary reference. The artefact used was an Instromet Rotary Piston Prover (IRPP), which was calibrated in the flow rate range of 5 m^3/h – 200 m^3/h, and a pressure range of 8 barg – 60 barg. None of the normalized differences are above the critical level, and they agree with 90 % confidence. This supports the CMC claim of the applicant (VSL) laboratory. Future intercomparisons at primary level with three participants are planned by the European Reference for Gas Metering (EuReGa) partners [1] to further corroborate existing CMC claims of participating laboratories.

Intercomparison of primary standards with high-pressure natural gas

In addition to the existing intercomparisons [2, 3] the EuReGa experts' team aims to further demonstrate the equivalence of the primary standards. The first intercomparison at primary level was performed using turbine meters as artefact [4, 5]. EuReGa partners VSL and FORCE decided to further corroborate VSL's existing calibration and measurement capability using an Instromet Rotary Piston Prover, which are often used as transfer standards for providing high-pressure natural gas flow traceability at flow rates exceeding primary standard flow rates at 200 m^3/h – 400 m^3/h. PTB agreed to take the role of the independent third party, overseeing the results of this intercomparison of VSL and FORCE. It is emphasized at this point that the current work is about an intercomparison at primary level only. Harmonization at primary level is not pursued, rather harmonization of facilities of the European Reference for Gas metering (EuReGa) partners for high-pressure flow rates of several 10000's m^3/h is performed as part of EURAMET TC Flow project 1301 [1].

Participants' Piston Provers

VSL and FORCE use a piston prover as primary reference. The characteristics of these provers are listed in Table 1.

Table 1: Characteristics of the participants' piston provers. All provers are operated on natural gas.

Institute	VSL	FORCE
Primary device	24" Gas Oil Piston Prover (GOPP)	26" Twin Piston Prover
Piston	Passive	Active
Nominal diameter	600 mm	660 mm
Absolute operating pressure	1 bar – 62 bar	1 bar – 66 bar
Piston stroke / Effective stroke	12 m / 6.5 m	2.8 m / 0.6 – 2.7 m
Flowrate range	5 m^3/h – 230 m^3/h	2 m^3/h – 400 m^3/h
Maximum piston speed	0.25 m/s	0.17 m/s
CMC	0.06 % – 0.29 % *	0.080%

* 0.06 % - 0.09 % in range 40 m^3/h – 230 m^3/h

VSL uses a 24” Gas Oil Piston Prover (GOPP). The prover is filled with oil on one side and gas on the other side of the free moving piston. The maximum flowrate is 230 m^3/h. FORCE Technology uses a 26” Twin gas-gas Piston Prover with two parallel cylinders with bidirectional pistons inside them. The actuated pistons can displace up to 400 m^3/h.

Transfer meter and test protocol

An Instromet Rotary Piston Prover (IRPP) was used as artefact. The IRPP is a DUO rotary meter, where phase shifted pairs of impellers reside within a flexible membrane, absorbing most of the pulsation signals that are known to affect rotary meters. IRPPs are customarily used on the high-pressure natural gas primary standards of VSL and FORCE, and are known for their good reproducibility, repeatability, and long-term stability. Its flow rate range is 2 m^3/h – 400 m^3/h matching nicely with those of the primary standards. Based on repeated atmospheric air calibrations, the selected IRPP had proven long-term stability showing a maximum shift in measurement deviation *e* at 0.05 %. This value is based on the calibrations performed with atmospheric air shown in Figure 1. They were performed prior, in between, and after the calibrations conducted with high-pressure natural gas at the primary standards of VSL and FORCE.

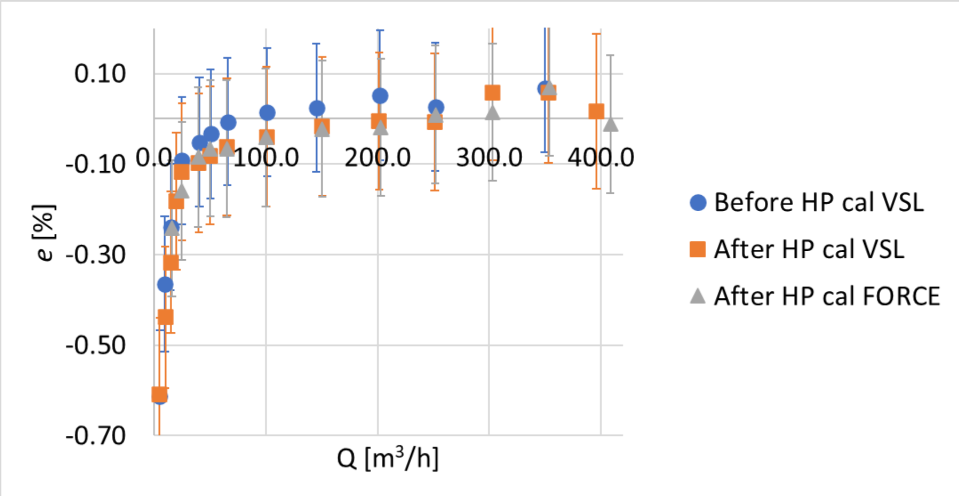

Figure 1: Meter deviation e [%] versus flow rate [m^3/h] obtained with air at atmospheric pressure before (blue circle), in between (orange square), and after (grey triangle) high-pressure natural gas calibrations at the primary standards of VSL and FORCE.

The combined uncertainty of calibration is indicated by the error bars. The meter was calibrated at flowrates 5 m^3/h, 10 m^3/h, 20 m^3/h, 50 m^3/h, 100 m^3/h, 150 m^3/h, and 200 m^3/h at gauge pressures 8 bar, 20 bar and 60 bar. At each flowrate the laboratories report the meter deviation *e*, which is the average of at least four measurements, and the expanded standard uncertainty of the mean (Type A uncertainty). VSL and FORCE cover the entire volumetric flow rate range. The natural gas compositions vary significantly between both laboratories. FORCE’s gas is relatively light, consisting predominantly of methane, while VSL’s methane content is at about 0.92 mol/mol. Consequently, volumetric flow rate was converted to Reynolds numbers. Figure 2 and Table 2 show the high-pressure calibration results, indicating an overall match within total calibration uncertainties indicated by the vertical uncertainty bars.

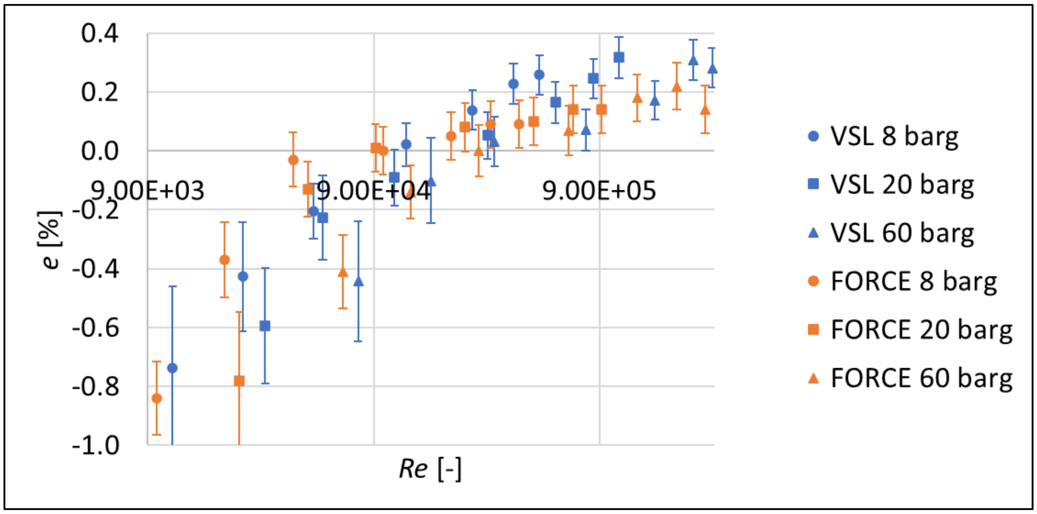

Figure 2: Meter deviation e [%] versus the Reynolds number [-] obtained with natural gas at high pressure. The symbol colors correspond to the participating laboratory and the symbol shapes to the calibration pressure. The combined uncertainty of calibration is indicated by the error bars.

Table 2: IRPP high-pressure natural gas calibration results obtained with VSL's and FORCE's primary standards.

Laboratory name	Nominal flowrate [m³/h]	Nominal pressure [barg]	Average Reynolds number [-]	Average deviation *e* [%]	Total calibration uncertainty *U* (*k* = 2) [%]
VSL	5	8	1.1565E+04	-0.74	0.28
VSL	10	8	2.3627E+04	-0.43	0.19
VSL	20	8	4.8692E+04	-0.21	0.09
VSL	50	8	1.2513E+05	0.02	0.07
VSL	100	8	2.4677E+05	0.14	0.07
VSL	150	8	3.7439E+05	0.23	0.07
VSL	200	8	4.8807E+05	0.26	0.07
VSL	5	20	2.9800E+04	-0.59	0.20
VSL	10	20	5.3424E+04	-0.23	0.14
VSL	20	20	1.1136E+05	-0.09	0.10
VSL	50	20	2.8691E+05	0.05	0.08
VSL	100	20	5.7395E+05	0.17	0.07
VSL	150	20	8.4776E+05	0.25	0.07
VSL	200	20	1.0958E+06	0.32	0.07
VSL	5	60	7.6728E+04	-0.44	0.20
VSL	10	60	1.6137E+05	-0.10	0.14
VSL	20	60	3.0871E+05	0.03	0.08
VSL	50	60	7.8382E+05	0.07	0.07
VSL	100	60	1.5825E+06	0.17	0.07
VSL	150	60	2.3432E+06	0.31	0.07
VSL	185	60	2.8408E+06	0.28	0.07
FORCE	5	8	9.8500E+03	-0.84	0.13
FORCE	10	8	1.9700E+04	-0.37	0.13
FORCE	20	8	3.9500E+04	-0.03	0.09
FORCE	50	8	9.8800E+04	0.00	0.08
FORCE	100	8	1.9800E+05	0.05	0.08
FORCE	150	8	2.9700E+05	0.09	0.08
FORCE	200	8	3.9700E+05	0.09	0.08
FORCE	5	20	2.2900E+04	-0.78	0.23
FORCE	10	20	4.5900E+04	-0.13	0.09
FORCE	20	20	9.1700E+04	0.01	0.08
FORCE	50	20	2.2900E+05	0.08	0.08
FORCE	100	20	4.5900E+05	0.10	0.08
FORCE	150	20	6.8900E+05	0.14	0.08
FORCE	200	20	9.2000E+05	0.14	0.08
FORCE	5	60	6.5700E+04	-0.41	0.13
FORCE	10	60	1.3100E+05	-0.14	0.09
FORCE	20	60	2.6300E+05	0.00	0.09
FORCE	50	60	6.5800E+05	0.07	0.08
FORCE	100	60	1.3200E+06	0.18	0.08
FORCE	150	60	1.9800E+06	0.22	0.08
FORCE	200	60	2.6400E+06	0.14	0.08

Data processing and results

The processing of the measurement data is done according to [6], which corresponds to the EuReGa implementation of one of the methods in [7]. The data analysis is performed in the Reynolds domain. For each combination of nominal pressure (8 barg, 20 barg and 60 barg) and Reynolds number, $\bar{e}$ is the weighted average of the deviations e observed by the labs, which makes $\bar{e}$ the reference level.

The deviations $d = e - \bar{e}$ with respect to the reference level ($e = \bar{e}$ or $d = 0$) versus the Reynolds number are graphically displayed in Figure 3. The deviation uncertainties are indicated by means of the vertical bars. For almost all data points these uncertainties bars intersect the reference level with 4 exceptions. An artefact long-term stability uncertainty of 0.05 % (*k* = 2) in reported meter deviation *e* was included into the data processing.

The Reynolds numbers match exactly as a consequence of the data processing procedure applied.

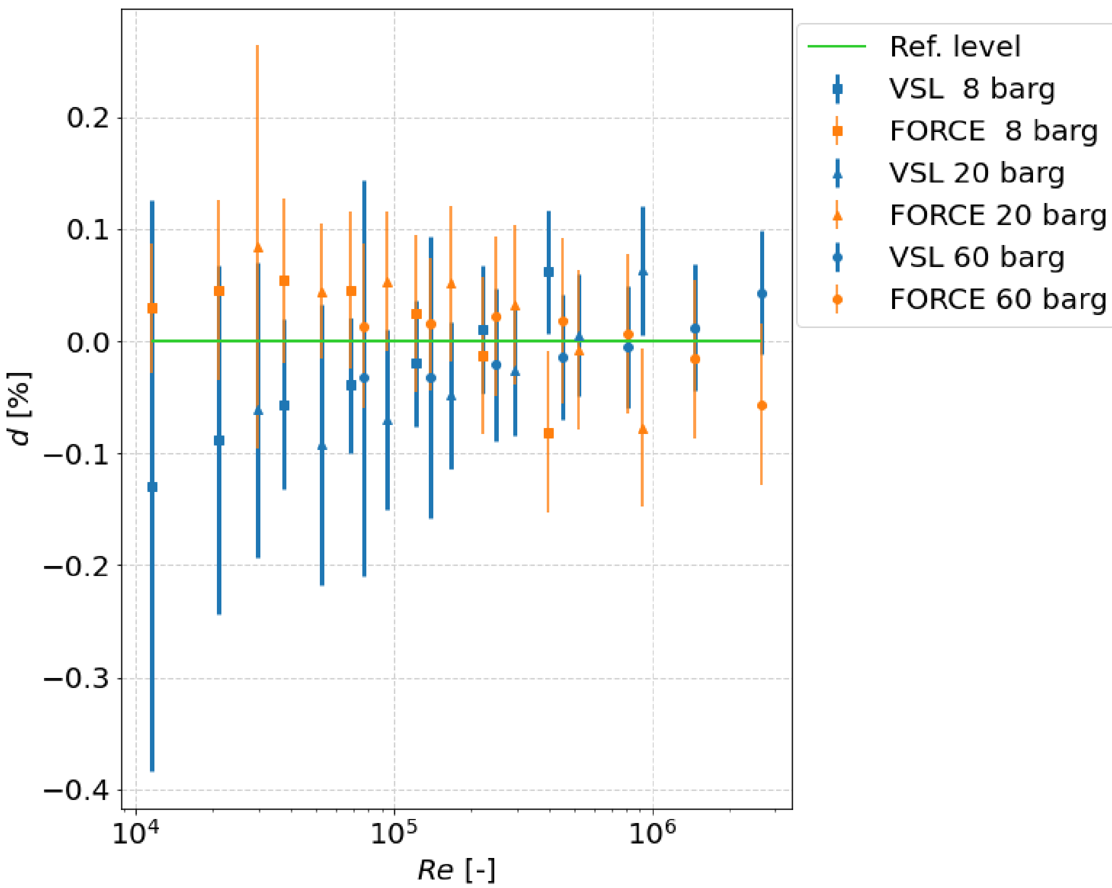

Figure 3: Deviations d [%] versus the Reynolds number [-]. The symbol colors correspond to the participating laboratory and the symbol shapes to the calibration pressure. The horizontal green line is the reference level d = 0.

The normalized deviations $E_n = d/U(d)$ are shown in Figure 4. Here E_n values are plotted versus the Reynolds number *Re*. Since only two laboratories participated to the intercomparison, the E_n values are by definition identical for both laboratories. This is indicated by orange markers with blue edges. Table 3 shows the frequency distribution of the observed E_n values. This table shows that circa 90 % of the results matches $E_n < 1$ and that that there are no $E_n > 1.2$ values. $E_n = 1$ is the warning level. About 10 % of E_n-values are above 1, therefore laboratories agree with 90 % confidence. Only two laboratories participated in the comparison, so that any significant systematic bias in the measurements and/or the data processing will translate into both laboratories showing a higher E_n value. Further research will be performed to unravel the causes for E_n values exceeding the warning level. In previous intercomparison, it was found that at least 95% of the data matches the $E_n \leq 1$ criterion [5].

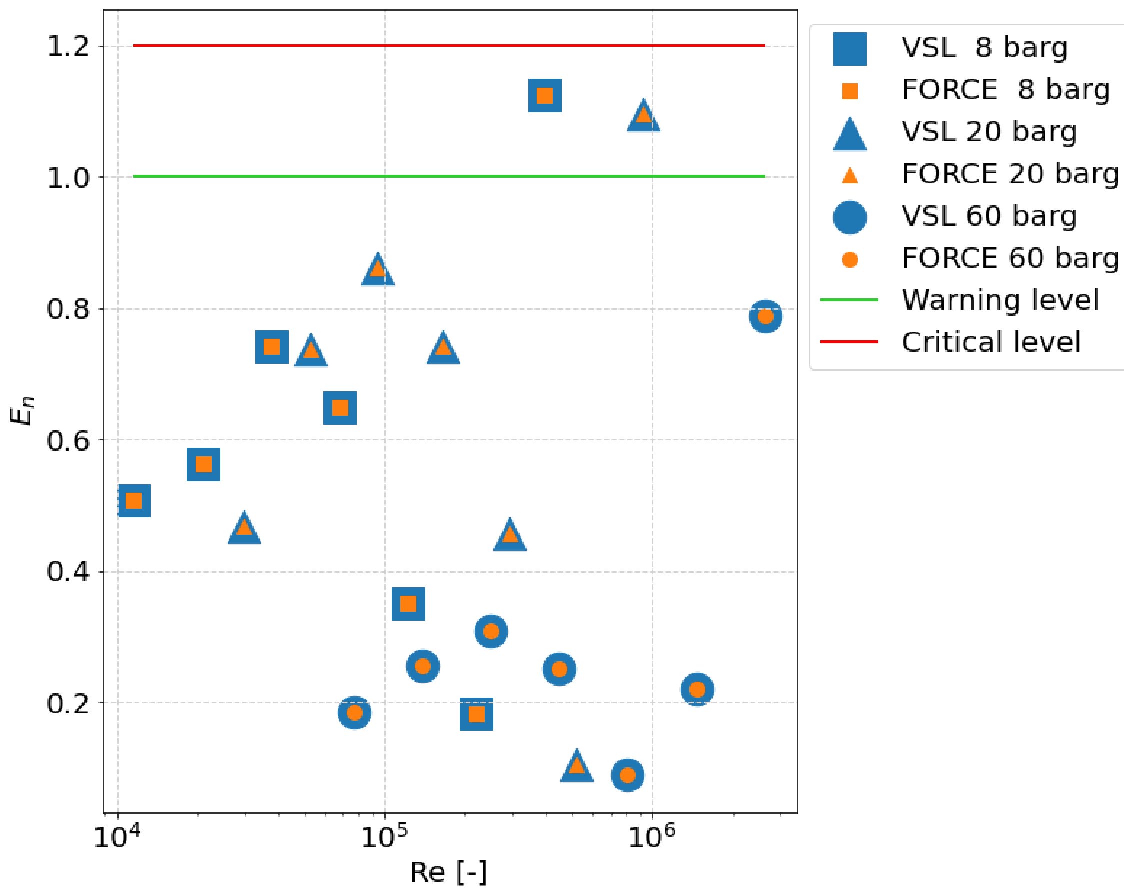

Figure 4: E_n values versus Reynolds number [-]. The green horizontal line is the warning level corresponding to $E_n = 1$. The horizontal red line is the critical level $E_n = 1.2$.

Table 3: Frequency distribution of observed E_n values

Histogram bin	**Number**	**Percentage**
$0 < E_n \leq 0.5$	26	61.9%
$0.5 < E_n \leq 1$	12	28.6%
$1 < E_n \leq 1.2$	4	9.5%
$E_n > 1.2$	0	0%
Total	**42**	**100%**

Discussion and conclusions

None of the normalized differences are above the critical level, and they agree with 90 % confidence. This supports the CMC claim of the applicant (VSL) laboratory. Thus, this intercomparison demonstrates that the second intercomparison between primary high-pressure gas flow standards is a success. Future intercomparisons at primary level with three participants are planned by the EuReGa partners to further corroborate existing CMC claims of participating laboratories.

Acknowledgements

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