Euramet.M.FF-S12
Project no. 1476

RMO supplementary comparison

Low pressure air flow between 25m³/h and 400 m³/h

Final Draft

Pilot

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Participants

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Contents

Introduction and purpose

The purpose of this Supplementary Comparison (SC) for "Low Pressure Air Flow" measurement is to support the Calibration and Measurement Capabilities (CMC) of the participating National Metrology Institutes and Designated Institutes according to CIPM MRA-G-13 [8]. The outcome of this comparison should lead to 'a clear and unequivocal' comparison of measurement results between participants.

The comparison was performed over the span of one year which started in March 2021 with the determination of the volume flow rate error of the test artifact by VSL. The test artifact was shipped to each participant where they also determined the volume flow rate error in turn. At the completion by all participants, the artifact was shipped back to VSL for a final calibration to show the stability of the artifact. The participants and timeline of the supplementary comparison are shown in Table 1.

Table 1. Participants and timeline

NMI/DI	Country	Contact	Test date [dd-mm-yyyy]
VSL[1)]	The Netherlands	Thomas Wendel	25-03-2021
LABSAGAS	Bosnia & Herzegovina	Ibrahim Busuladžić	24-05-2021
METAS	Switzerland	Marc de Huu	28, 29-06-2021
LNE-LADG	France	Christophe Windenberger	16-07-2021
PTB	Germany	Bodo Mickan	06-09-2021
VSL[2)]	The Netherlands	Thomas Wendel	04, 05-10-2021

[1)] First measurements at VSL, will be the results presented for the comparison reference values
[2)] Second results at VSL, will be used for the drift calculation

The travelling standard (TS)

The travelling standard is an Elster G400 IRM-3-DUO rotary gas meter which is a volumetric measuring device that works according to the positive displacement method.

Description summary of the travelling standard:

Make	: Elster
Type	: IRM-3 DUO
Size	: G400
Serial number	: 20528205
VSL identification	: Standard A
Process connection	: DN150
Qmax	: 650 m3/h
Impulse value	: 722 pulses = 1 m^3
Input	: 1x 24 Volts DC, 0.5 Ampere
Output	: 1x HF Pulse generator

The connection to the participant's calibration/test facility is DN150.

IRM-3 DUO

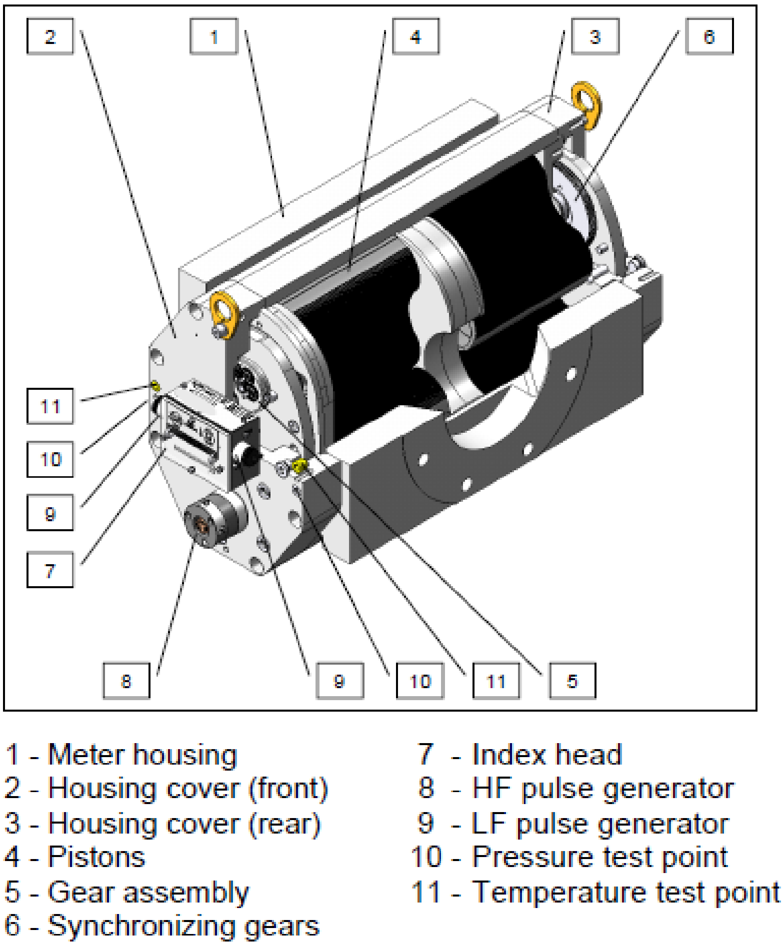


Figure 1. Drawing of the travelling standard

shipping container	***"As packaged"***	***HF pulse generator / pressure port***

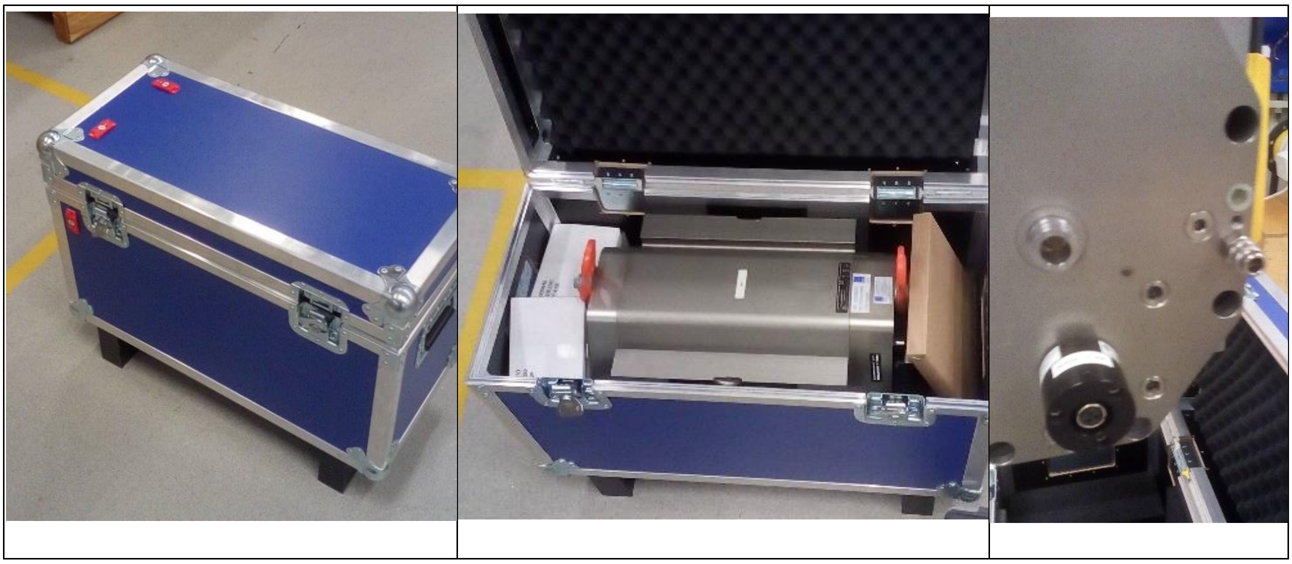


Figure 2. Pictures of the travelling standard

Measurement procedure

The reference value and flows

In the EURAMET.MM.F-S12 SC project the error of the travelling standard will be calculated from:

“The volume rate of a flowing gas passing through the travelling standard at given flows.”

The comparison reference values (CRV’s) will be evaluated following the principles laid down in, Metrologia 39 (2002), “*Proposed guidelines for the evaluation of key comparison data*” [4], and Metrologia 53 (2016), “*Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons*” [6].

The principles of analysis

- The before and after results obtained by the pilot laboratory will be used to calculate the drift behaviour of the travelling standard.
- The results provided by all participants will be given under actual conditions.
- For the calculation of the CRV’s, the weighted mean over all participants will be used.
- If for a result, the uncertainty contribution due to the traceability to another participant amounts to a substantial part of the overall uncertainty value, the result is not considered in the calculation of the CRV’s.

The results are calculated as measurement errors at the reference flows of each participant. The measurement errors are calculated for the travelling standard flow meter making use of the pulse output. The travelling standard is set up with a base impulse value set to 722 pulses per cubic meter.

Methods used for calibration

Each participant provided the pilot laboratory with a description and a simplified P&ID drawing to show how the travelling standard was connected to the participant’s test facilities. The facilities and method of calibration are described in 0. All participants have an independent traceability in the realization of their standards.

An overview of the calibration methods of the participating laboratories is presented in Table 2**Error! No bookmark name given.**.

Table 1. Methods used for calibration

NMI/DI	Indication	Country	Method	Standard	CMC CIPM MRA Database
VSL	3	The Netherlands	Volumetric - FSF	Volume bell prover	0.09 %
LABSAGAS	5	Bosnia & Herzegovina	Volumetric - FSF	Rotary gas meter	0.35 %
METAS	1	Switzerland	Volumetric - FSF	Volume bell prover	0.12 %
LNE-LADG	4	France	Volumetric - FSF	Critical flow nozzles	0.21 %
PTB	2	Germany	Volumetric - FSF	Critical flow nozzles	0.08 %

Test points

The flow rates shown in Table 3 are used for this supplementary comparison on air. All participants were able to generate the requested flow rates. The flow rates were not performed in the given order for all participants. The repeatability at each comparison reference value is used to calculate the combined uncertainty as presented by each participant.

Table 2. Flow rates and number of repeats for the comparison reference values

Flowrate (m³/h)	Number of Repeats	Remarks
25	3	--
40	3	--
65	10	comparison reference value
100	3	--
160	10	comparison reference value
250	3	--
325	3	--
400	10	comparison reference value

Data Analysis

The standardized Degree of Equivalence (E_n) is found for each comparison reference value separately. The data have been processed using ‘Procedure A’ of, ‘*the recommended guidelines for the evaluation of key comparison data*’ [4].

The difference (d_i) between the result of the CRV’s and the corresponding uncertainty $U(d_i)$ are calculated to form the Degree of Equivalence (DoE) which is the combination (d_i, $U(d_i)$) (see next section). The (E_n) value has been used to show whether the participants results are consistent with the comparison reference values. Consistency is shown when $E_n \leq 1$. If $1 < E_n \leq 1.2$ a warning level is defined. With $E_n > 1.2$ the results are inconsistent with the reference value.

An added measure of (conclusive / inconclusive) results is presented based on the content probability of overlapping Gaussian probability distributions of each participants results (P_i) compared to the Gaussian probability distribution of the comparison reference values following the information in Metrologia 53 (2016) [6]. Criterion ‘D’ in Metrologia 53 is that $P_i \geq 0.35$ when assessing $E_n \leq 1$ values for the results to be conclusive.

The determination of the difference (DoE)

The data have been evaluated for normality and there was one set of averaged data from one lab that did not meet the normality test. As this set of averaged data are not used as a comparison reference value, it did not influence the results of this comparison. The weighted mean of the participants results is calculated, and a chi-squared test has been applied to accept the results as the comparison reference values. The differences (d_i) between the results of the participants (x_i) and the comparison reference values (x_{ref}) are calculated according to

$$d_i = x_i - x_{ref} \tag{1}$$

The calculation of the DoE needs information about the uncertainty of the difference (d_i) found in equation (*1*). To make statements about the uncertainty of the difference (d_i), it is necessary to consider first the general problem of the difference of two values x_1 and x_2. If we look to the pure propagation of standard uncertainty, we find:

$$u_{x_1-x_2}^2 = \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} & \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} \begin{pmatrix} u_1^2 & cov \\ cov & u_2^2 \end{pmatrix} \begin{pmatrix} \frac{\partial(x_1-x_2)}{\partial x_1} \\ \frac{\partial(x_1-x_2)}{\partial x_2} \end{pmatrix} = u_1^2 + u_2^2 - 2 \times cov \tag{2}$$

The standard uncertainty of the difference is the quadratic sum of the uncertainties of the inputs (u_1 and u_2). Each participating labs result are considered independent, so in this case the covariance (cov) is considered zero leading to:

$$u_{x_1-x_2}^2 = u_1^2 + u_2^2 \qquad (3)$$

Equation (3) uses the standard uncertainties. The expanded uncertainty $U(d_i)$ is based on a coverage factor 2 giving an approximate 95 % coverage interval and is found by:

$$U(d_i) = 2 \times u(d_i) \qquad (4)$$

Based on the differences and the corresponding uncertainties, the standardized Degree of Equivalence (or normalized deviation) can be calculated according to:

$$E_n = \left|\frac{d_i}{U(d_i)}\right| \qquad (5)$$

Measurement results

Each participant used their own method of calibration (see Table 2). Fluid pressure and temperature was measured together with the pulse output at the transfer standard to calculate the reference volume flow rate passing through the transfer standard to calculate the volume flow rate errors.

Stability of the transfer standard

The stability of the transfer standard has been calculated based on two tests performed by VSL during the comparison. The tests were performed before the start of the comparisons and after the transfer standard was returned from the last comparison laboratory. The stability of the transfer standard has been calculated using the maximum difference between the two measurement errors found by VSL for each flow rate using a rectangular distribution according to Metrologia 53 (2016) [6].

$$u_{drift} = \frac{\varepsilon_{max} - \varepsilon_{min}}{\sqrt{3}} \qquad (6)$$

The contribution u_{drift} to the uncertainty of the laboratory results is determined to be 0.032 % ($k=1$).

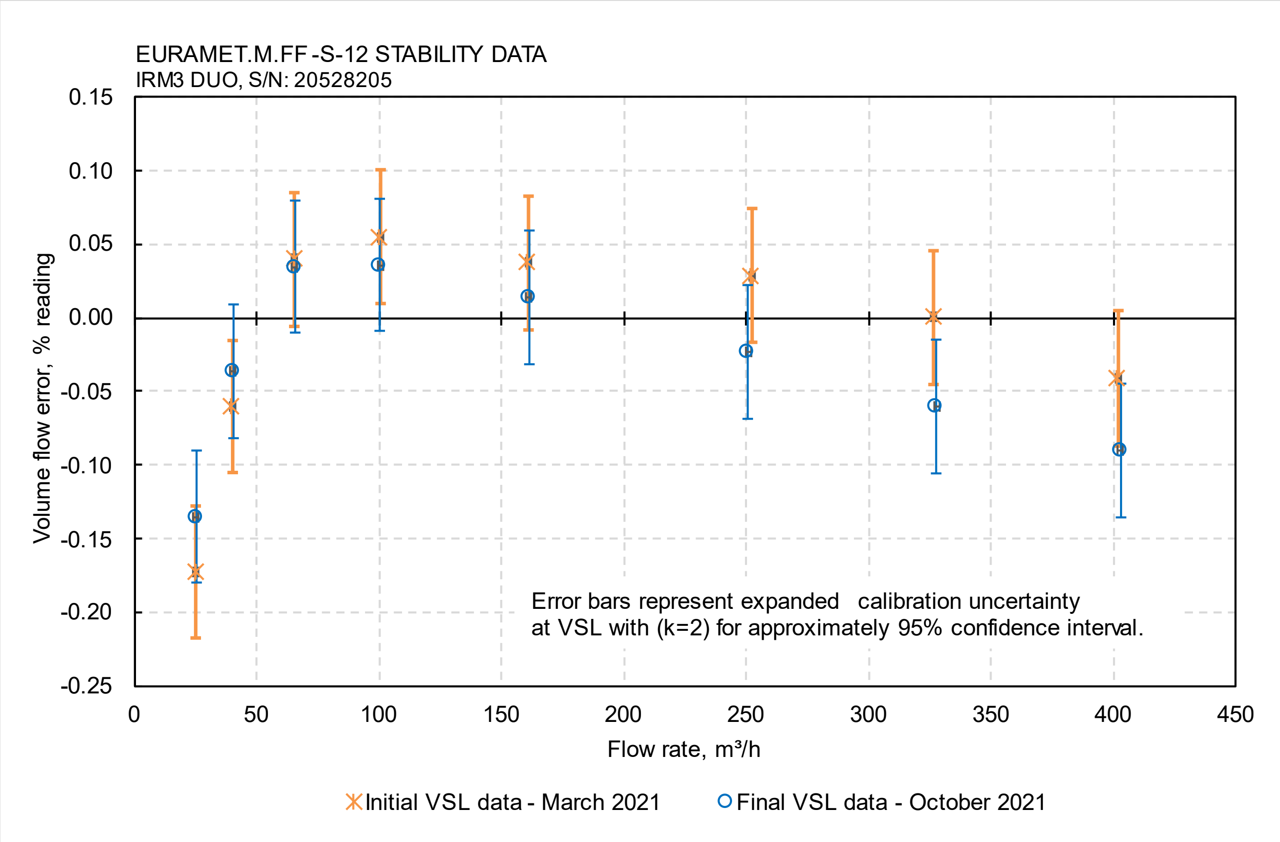


Figure 3. Test results to calculate the stability of the transfer standard

Participant Results

The results presented below are from the data collected during the EURAMET.M.FF-S12 comparison. The results are shown in progressive order for analyzing the data and confirming the use of 'Procedure A' of, '*the recommended guidelines for the evaluation of key comparison data*' [4] when calculating the comparison reference values. The 'Summary Data' includes *Figure 4* for comparing the volume flow rate error values for all participating labs. The 'Normality Checks' include *Figure 5* for comparing the 'Q-Q Plots' [7] for each lab which are used to satisfy condition 3 of the Cox conditions of use for the application of procedure 'A'. The 'Comparison Reference Values contains *Table 4*, showing results of the Cox procedure 'A' with the weighted mean values including the results of the chi-squared test used to accept these values.

Summary Data

Table 4. Summary results for each participant

METAS

Ref. flow rate [m³/h]	Error Rate [%]	u_A [%]	u_B [%]	U [%]
25.7	-0.138	0.011	0.060	0.122
40.9	-0.041	0.017	0.060	0.125
65.2	-0.006	0.007	0.060	0.121
99.9	-0.016	0.014	0.060	0.123
159.3	0.003	0.005	0.060	0.120
251.2	-0.031	0.009	0.060	0.121
325.5	-0.038	0.004	0.060	0.120
399.1	-0.048	0.004	0.060	0.120

PTB

Ref. flow rate [m³/h]	Error Rate [%]	u_A [%]	u_B [%]	U [%]
25.7	-0.123	0.0011	0.040	0.080
41.2	-0.034	0.0024	0.040	0.080
67.0	0.050	0.0004	0.040	0.080
103.7	0.063	0.0009	0.040	0.080
165.4	0.085	0.0004	0.040	0.080
256.6	-0.008	0.0007	0.040	0.080
333.5	-0.032	0.0008	0.040	0.080
411.0	0.027	0.0004	0.040	0.080

VSL

Ref. flow rate [m³/h]	Error Rate [%]	u_A [%]	u_B [%]	U [%]
25.1	-0.17	0.004	0.047	0.093
39.9	-0.06	0.004	0.047	0.093
65.5	0.04	0.003	0.047	0.093
100.4	0.06	0.004	0.047	0.093
160.9	0.04	0.002	0.047	0.093
252.1	0.03	0.006	0.047	0.094
326.7	0.00	0.002	0.047	0.093
402.2	-0.04	0.007	0.047	0.094

LNE-LADG

Ref. flow rate [m³/h]	Error Rate [%]	u_A [%]	u_B [%]	U [%]
24.7	0.033	0.002	0.105	0.210
39.6	0.039	0.002	0.105	0.210
64.5	0.161	0.003	0.105	0.210
99.5	0.124	0.000	0.105	0.210
159.2	0.054	0.003	0.105	0.210
246.7	-0.026	0.003	0.105	0.210
322.5	-0.141	0.004	0.105	0.210
398.0	-0.205	0.002	0.105	0.210

LABSAGAS

Ref. flow rate [m³/h]	Error Rate [%]	u_A [%]	u_B [%]	U [%]
25.1	-0.184	0.001	0.123	0.245
40.4	-0.120	0.002	0.118	0.236
65.1	-0.037	0.002	0.108	0.215
100.1	-0.040	0.002	0.106	0.212
160.5	0.001	0.002	0.105	0.210
250.5	-0.021	0.002	0.105	0.210
325.9	-0.068	0.000	0.145	0.290
399.5	-0.087	0.002	0.145	0.289

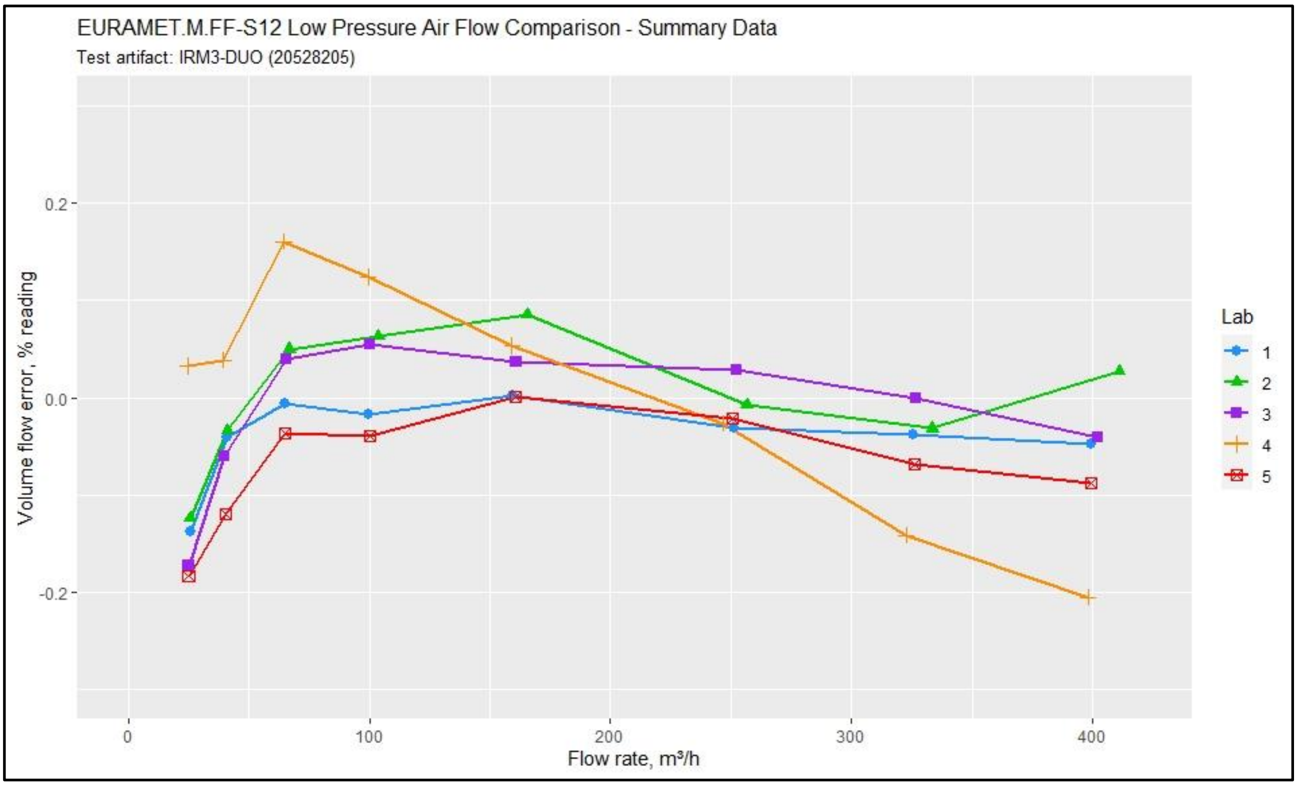
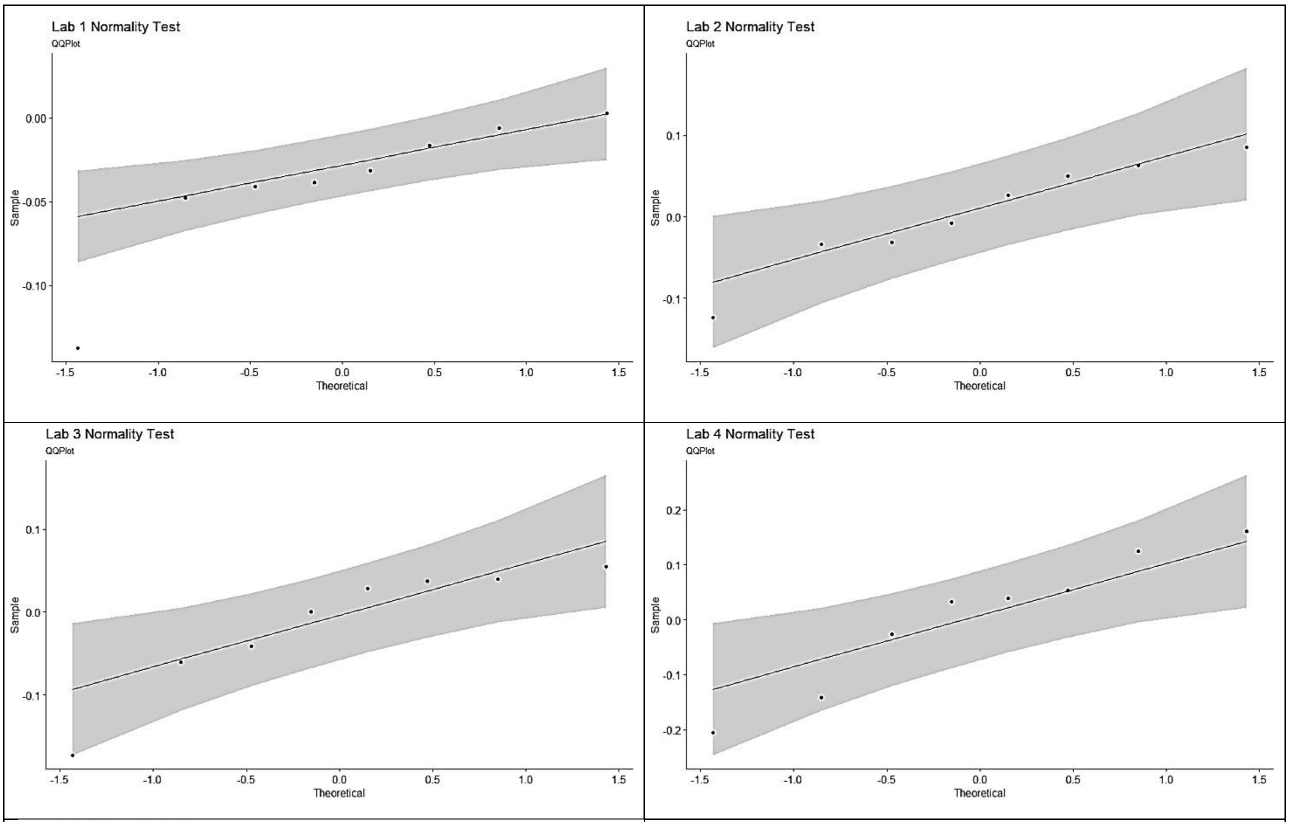
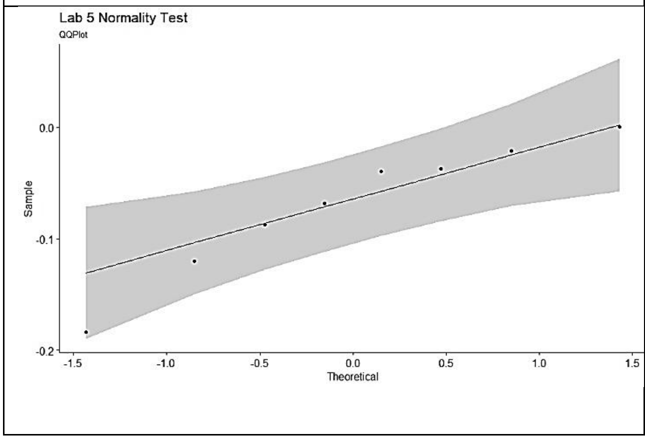


Figure 4. Measurement error from all labs, as the indication of the labs is in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5)

Normality Checks





Shapiro test

Lab	variable	statistic	p-value
METAS (1)	Error	0.801	0.029
PTB (2)	Error	0.943	0.636
VSL (3)	Error	0.846	0.087
LNE (4)	Error	0.935	0.567
LABSAGAS (5)	Error	0.934	0.567

The p-value > 0.05 implies that the distribution of the data are not significantly different from normal distribution.

Figure 5. Q-Q Plots and results of Shapiro-Wilk normality test. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5)

Comparison Reference Values

Table 5. Cox method procedure A results with chi-squared test

Average Flowrate [m³/h]	CRV Weighted Mean Error [%]	CRV Uncertainty (k=1) [%]	Chi-squared observed	Chi-squared with 4 degrees of freedom [95%]
65.5	0.038	0.031	2.16	0.71
161.1	0.046	0.030	1.19	0.71
402.0	-0.033	0.031	4.01	0.71

Degrees of Equivalence (DoE) and Evaluation Number (En value)

The degrees of equivalence have been found as described in Section 4 for each participant as listed in below in Table 6. All uncertainty values are shown as *k=1*.

Table 6. Average values at the comparison reference flow rates.

Lab	Rate [m³/h]	x_i [%]	u_A [%]	u_B [%]	u_{drift} [%]	u_{xi} [%]	d_i [%]	u_{di} [%]	$\lvert E_n \rvert$
METAS	65.2	-0.01	0.007	0.06	0.03	0.07	-0.04	0.06	0.39
PTB	67.0	0.05	0.000	0.04	0.03	0.05	0.01	0.03	0.18
VSL	65.5	0.04	0.003	0.05	0.03	0.06	0.00	0.04	0.02
LNE-LADG	64.5	0.16	0.003	0.11	0.03	0.11	0.12	0.10	0.60
LABSAGAS	65.1	-0.04	0.002	0.11	0.03	0.11	-0.07	0.11	0.35
METAS	159.3	0.00	0.005	0.06	0.03	0.07	-0.04	0.05	0.43
PTB	165.4	0.09	0.000	0.04	0.03	0.05	0.04	0.02	0.87
VSL	160.9	0.04	0.002	0.05	0.03	0.06	-0.01	0.03	0.13
LNE-LADG	159.2	0.05	0.003	0.11	0.03	0.11	0.01	0.10	0.04
LABSAGAS	160.5	0.00	0.002	0.11	0.03	0.11	-0.05	0.10	0.23
METAS	399.1	-0.05	0.004	0.06	0.03	0.07	-0.02	0.06	0.13
PTB	411.0	0.03	0.000	0.04	0.03	0.05	0.06	0.04	0.75
VSL	402.2	-0.04	0.007	0.05	0.03	0.06	-0.01	0.05	0.09
LNE-LADG	398.0	-0.21	0.002	0.11	0.03	0.11	-0.17	0.11	0.82
LABSAGAS	399.5	-0.09	0.002	0.14	0.03	0.15	-0.05	0.14	0.19

The degrees of equivalence for each participant, with error bars as $2 \times u(d_i)$, of are shown in Figures 6, 7 and 8.

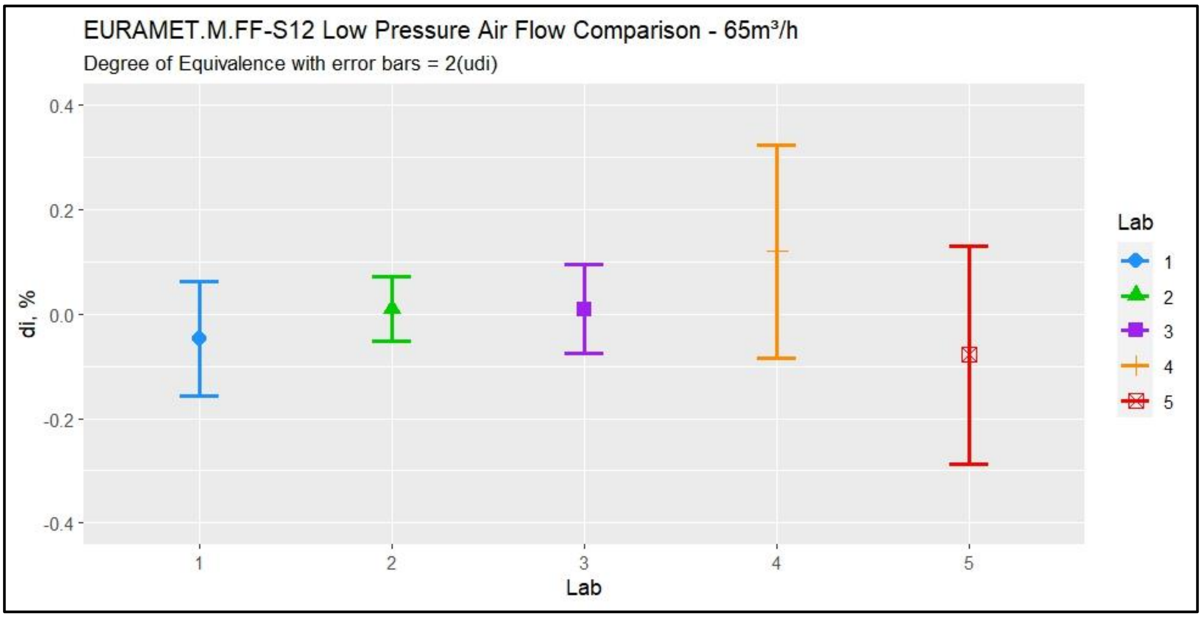


Figure 6. Degrees of equivalence at 65 m³/h. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5).

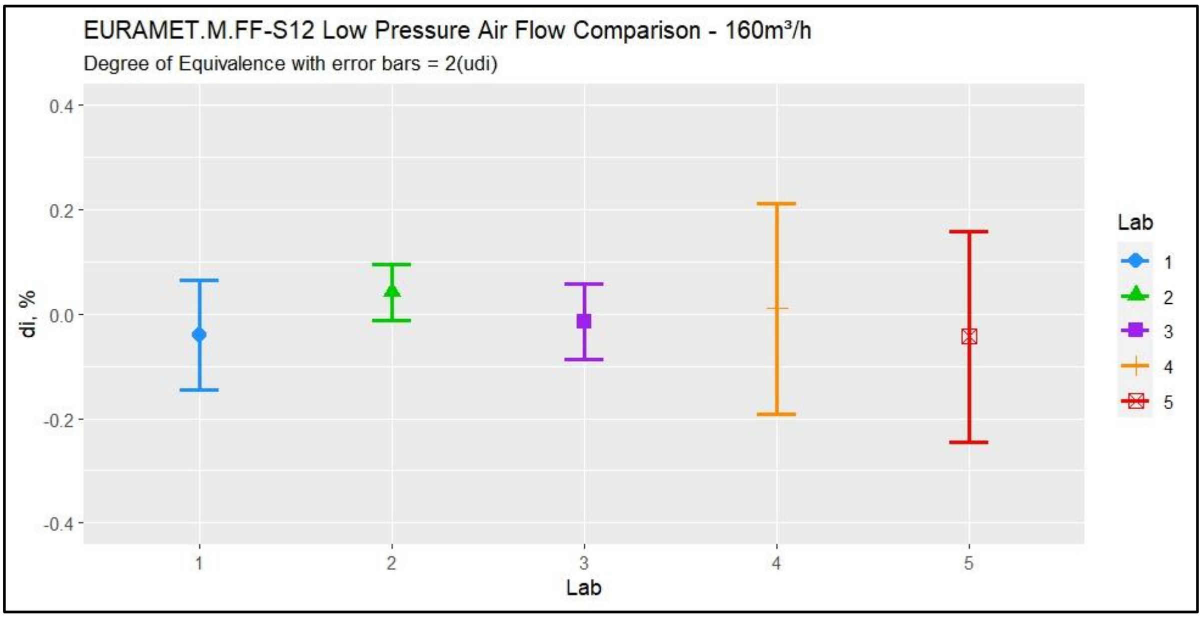


Figure 7. Degrees of equivalence at 160 m³/h. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5).

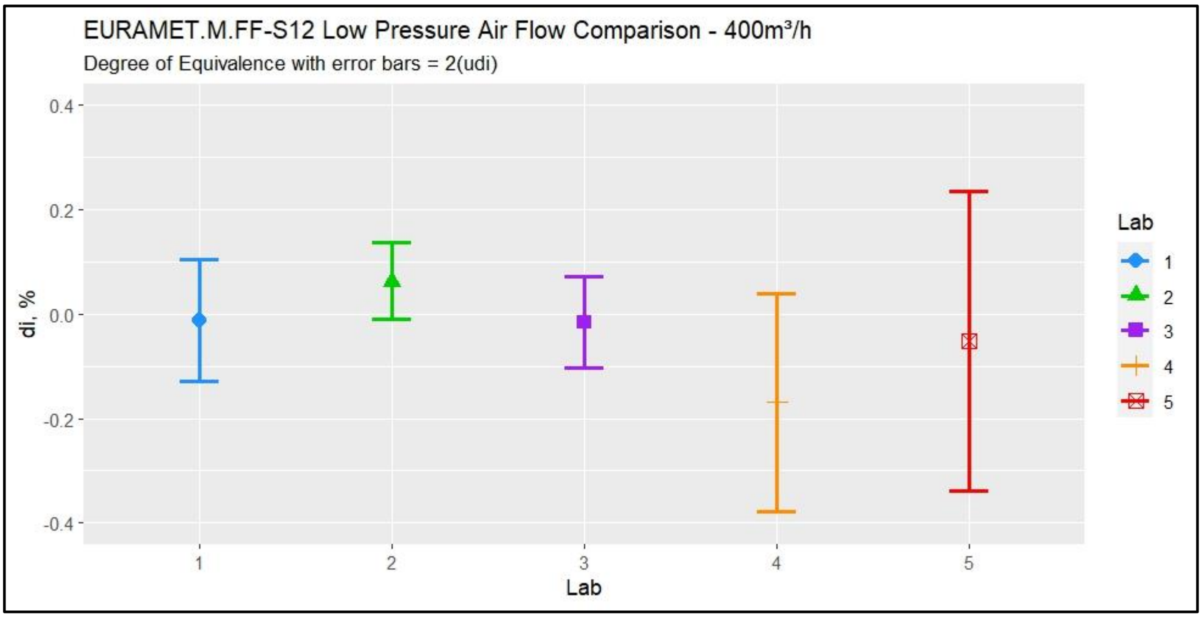


Figure 8. Degrees of equivalence at 400 m³/h. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5).

Probability Distributions

The paper, "Transfer standard uncertainty can cause inconclusive inter-laboratory comparisons", Metrologia 53 (2016) [6] provides alternative methods for assessing the results of inter-laboratory comparisons. The focus of the paper is about inconclusive results based on large transfer standard uncertainties, which is not necessarily the case for this comparison but there is a significant difference between the participant lab with the lowest CMC (0.08 %, *k=2*) and the participant lab with the largest CMC (0.35 %, *k=2*). The overlaps in estimated Gaussian probability distributions between the participant results and the CRV values are presented. The probability distributions are estimated from the laboratories reported values of (x_i) and (u_{xi}) as the mean and standard deviation. The probability distribution of the comparison reference values is estimated using the weighted mean value and the uncertainty of the weighted mean. Figures 10, 11 and 12 show the overlap in probability distributions at each CRV flow rate.

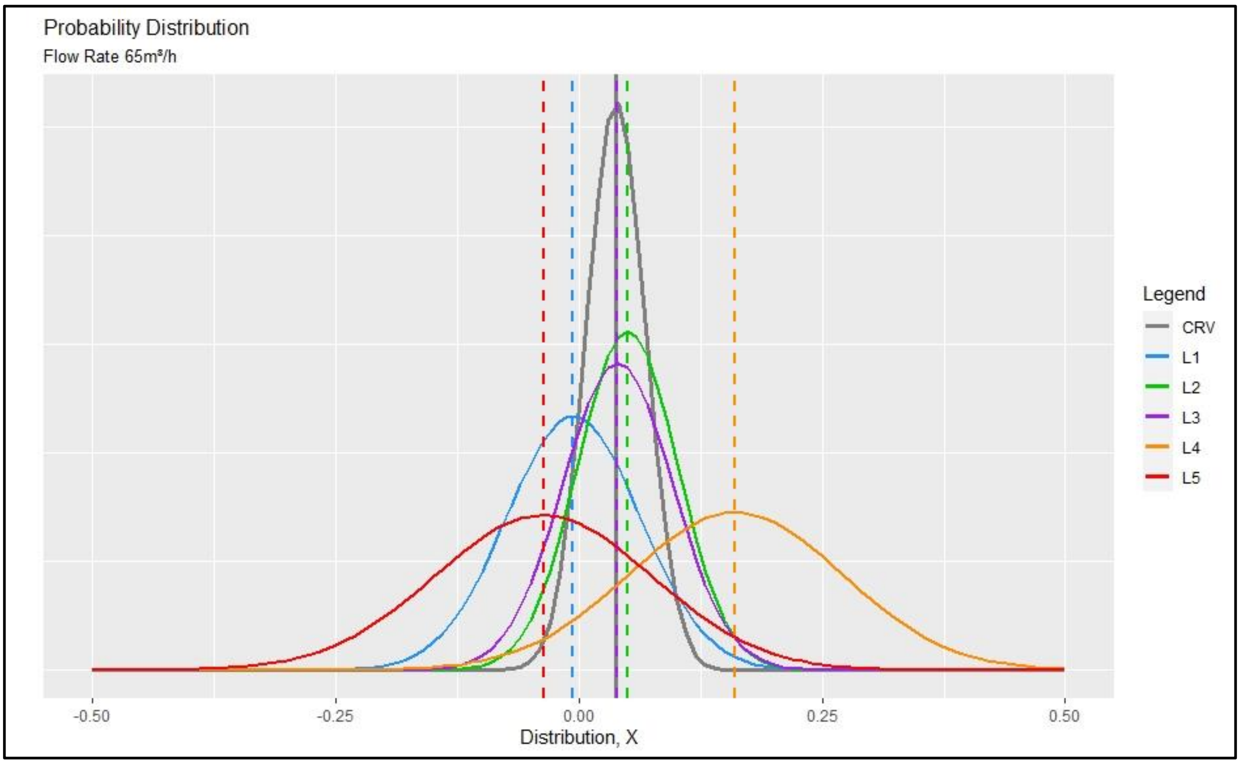


Figure 10. Gaussian probability distribution at 65 m³/h. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5).

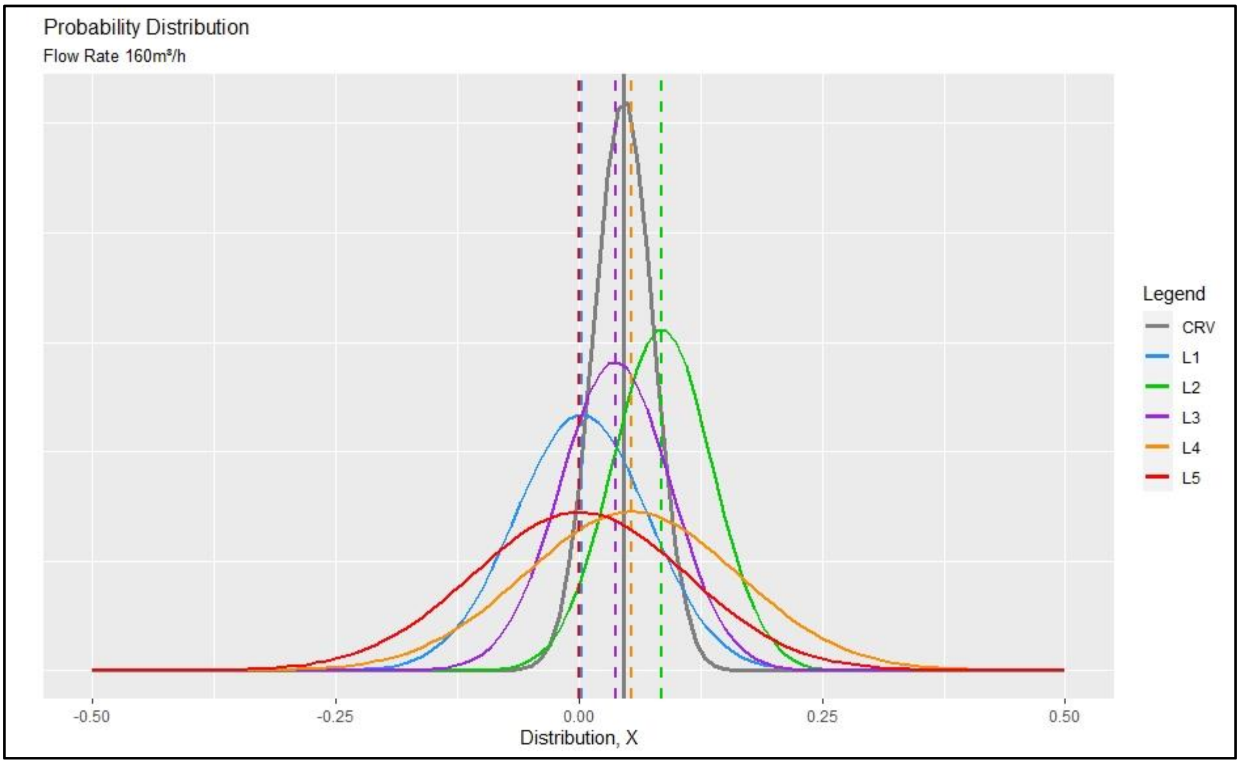


Figure 11. Gaussian probability distribution at 160 m³/h. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5)

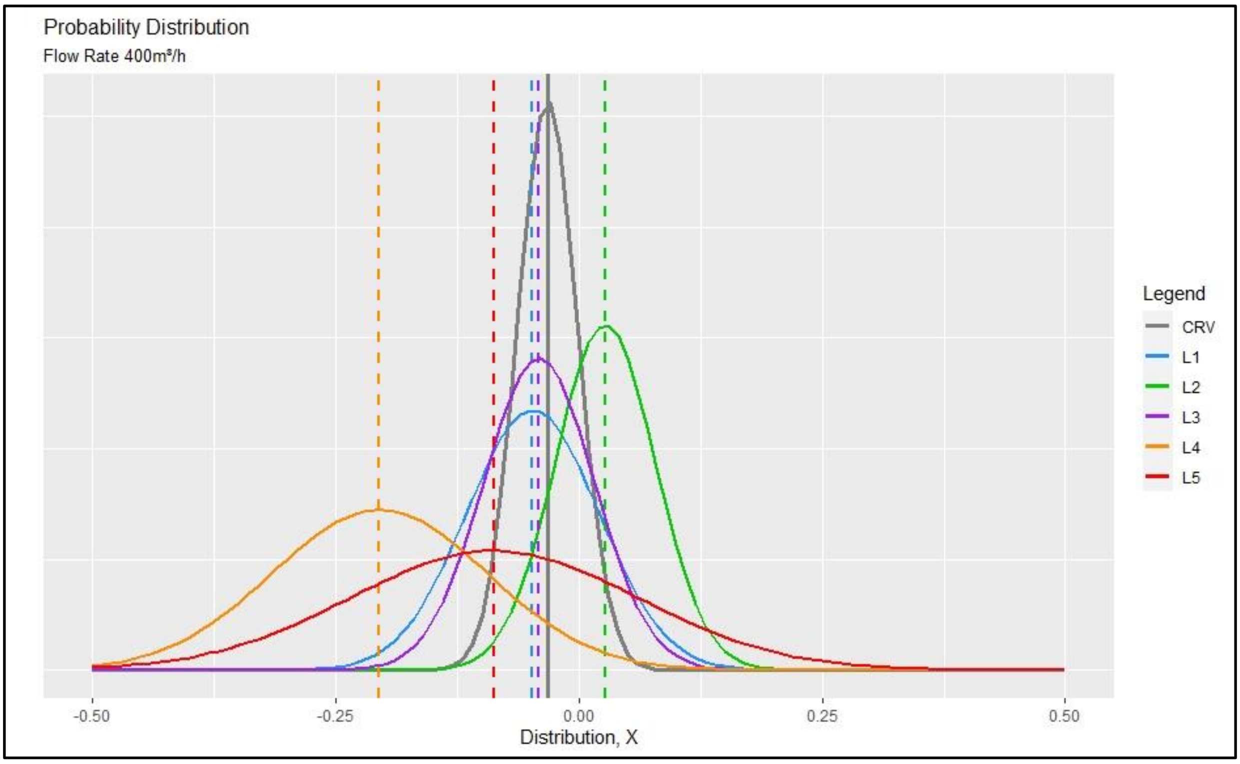


Figure 12. Gaussian probability distribution at 400 m³/h. The labs are indicated in order: METAS (1), PTB (2), VSL (3), LNE (4) and LABSAGAS (5)

The content of probability of overlap between each participating laboratory and the CRV probability distribution has been calculated and presented in Table 7.

Table 7. Content probability

Flowrate [m³/h]	METAS [P_i]	PTB [P_i]	VSL [P_i]	LNE-LADG [P_i]	LABSAGAS [P_i]
65	0.53	0.74	0.71	**0.27**	0.37
160	0.54	0.58	0.70	0.45	0.42
400	0.63	0.45	0.71	**0.17**	0.35

Conclusion

Euramet Project no.1476 compares the reference volume flow rates of five calibration laboratories using low pressure air at 65 m³/h, 160 m³/h and 400 m³/h. This comparison was performed as a supplementary comparison to confirm the claimed CMC values for each participating laboratory.

The results of this comparison meet the Cox method ‘A’ for evaluation of comparison data [4] that the Degree of Equivalence between participants should be smaller than 1 ($E_n \leq 1$), which supports the claimed CMC values. However, due to the relatively broad range in CMC values between the participating laboratories, Criterion ‘D’ from Metrologia 53 (2016) [6] has been applied and shows two of the results from LNE-LADG are considered inconclusive based on the content probability of (P_i) being < 0.35.

References

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Abbreviations and definitions

BIPM = Bureau International des Poids et Mesures (the International Bureau of Weights and Measures)
CCM = Consultative Committee for Mass and Related Quantities
CIPM = Comité International des Poids et Mesures (International Committee for Weights and Measures)
CMC = Calibration and Measurement Capabilities
DI = Designated Institute
DoE = Degree of Equivalence
FF = Fluid Flow
FSF = Flying Start Finish method
GUM = Guide to the Expression of Uncertainty in Measurement [1]
KC = Key Comparison
KCRV = Key Comparison Reference Value
MRA = Mutual Recognition Arrangement
NMI = National Metrology Institute
RTD = Resistive Temperature Device
SSF = Standing Start Finish method
TS = Transfer Standard
VIM = Vocabulaire International de Metrologie
VSL = The National Metrology Institute of the Netherlands
WGFF = Working Group for Fluid Flow under CCM of BIPM

Annex 1. Data of the stability tests

25, 26 March 2021

Initial Summary					
Avg	Avg	Avg	Avg	StdDev	Count
Rate	Inlet Press	Inlet Temp	Error	Mean	
[m³/h]	[bar(g)]	[°C]	[%]	[%]	[n]
402.01	0.02	20.13	-0.04	0.007	10
326.68	0.02	20.25	0.00	0.002	3
252.17	0.02	20.23	0.03	0.006	3
160.94	0.02	20.25	0.04	0.002	10
100.48	0.02	20.22	0.06	0.004	3
65.49	0.02	20.18	0.04	0.003	5
39.90	0.02	20.16	-0.06	0.004	3
25.08	0.02	20.15	-0.17	0.004	3

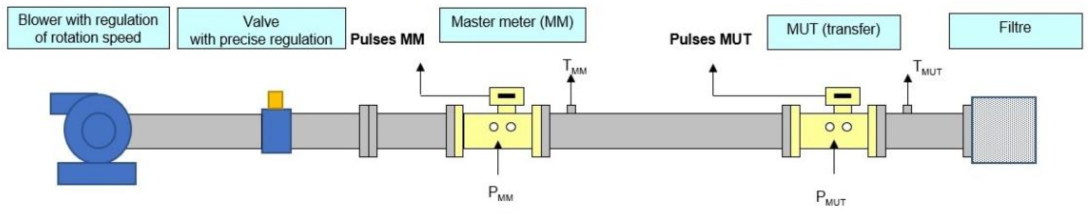
04, 05 October 2021

Final Summary					
Avg	Avg	Avg	Avg	StdDev	Count
Rate	Inlet Press	Inlet Temp	Error	Mean	
[m³/h]	[bar(g)]	[°C]	[%]	[%]	[n]
402.97	0.02	20.28	-0.09	0.004	10
327.73	0.02	20.33	-0.06	0.007	3
250.84	0.02	20.35	-0.02	0.006	3
161.03	0.02	20.38	0.01	0.002	10
100.48	0.02	20.34	0.04	0.001	3
65.32	0.02	20.38	0.03	0.002	10
40.30	0.02	20.40	-0.04	0.002	3
25.09	0.02	20.23	-0.14	0.005	3

Annex 2. Test facilities

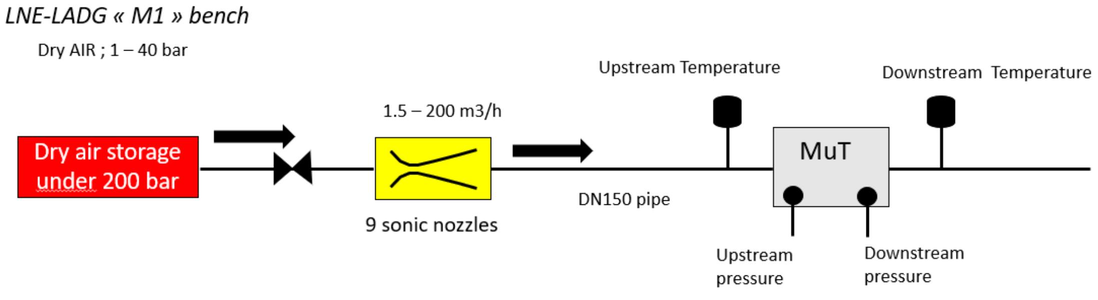
Bosnia & Herzegovina (Euramet)	**LABSAGAS** Contact: Dr Ibrahim Busuladžić Technical manager of laboratory (e: ibusuladzic@sarajevogas.ba, t: +387 33 568 125) **Shipping address:** LABSAGAS – Laboratory for measuring Instruments KJKP Sarajevogas d.o.o. Rajlovačka bb 71000 Sarajevo Bosnia and Herzegovina
France (Euramet)	**Cesame Exadébit (LNE-LADG)** Contact: Christophe Windenberger Technical manager (e: c.windenberger@cesame-exadebit.fr, t: +33(0) 5 49 37 91 26) **Shipping address:** Cesame Exadébit SA 43 rue de l'Aérodrome 86000 POITIERS France
Germany (Euramet)	**PTB** Contact: Bodo Mickan (e: Bodo.Mickan@ptb.de, t:) **Shipping address:** Physikalisch-Technische Bundesanstalt (PTB) Bundesallee 100 38116 Braunschweig Germany
Switzerland (Euramet)	**METAS** Contact: Marc de Huu Head of laboratory Flow and Hydrometry (e: marc.dehuu@metas.ch, t: +41 58 387 02 67) **Shipping address:** Federal Institute of Metrology METAS Lindenweg 50, CH-3003 Bern-Wabern Switzerland
The Netherlands [pilot] (Euramet)	**VSL B.V.** Contact: Thomas Wendel Metrologist Flow Metrology (e: twendel@vsl.nl t: +316 21 58 72 23) **Shipping address:** VSL B.V. Thijsseweg 11 2629 JA Delft The Netherlands

LABSAGAS, Bosnia & Herzegovina



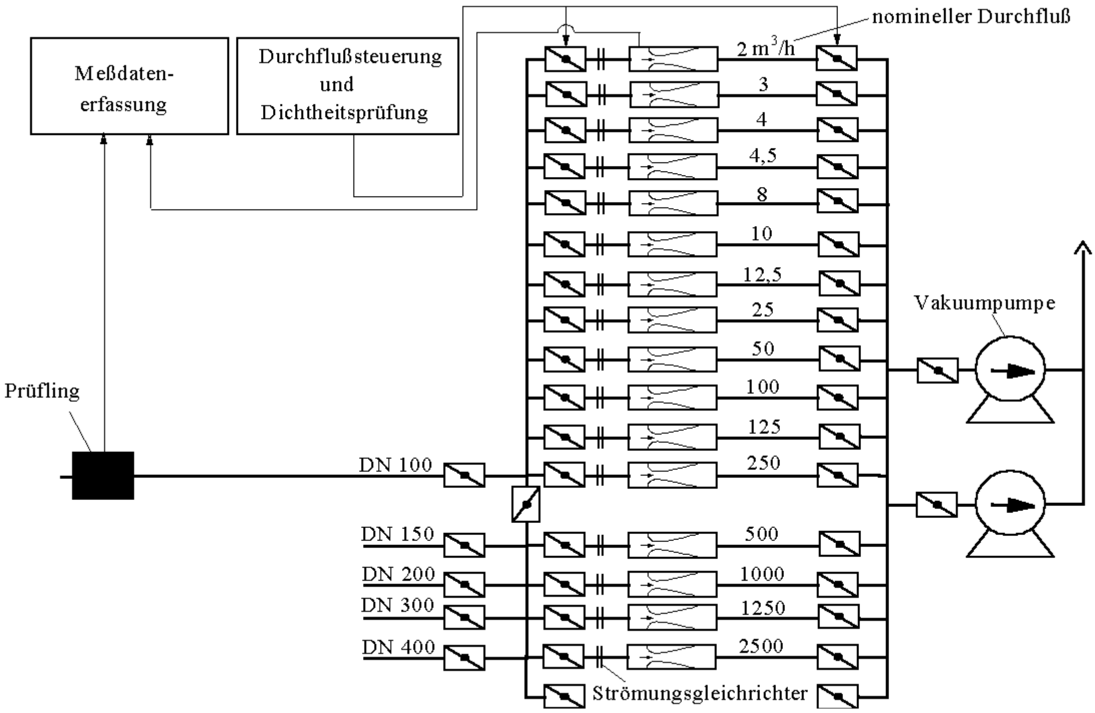
The test line for turbine and rotary gas meters, with reference gas meters was used for calibration.
The main characteristics of the facility: measurement range is (0,35 – 4000) m3/h, the calibration and measurement capability in the range of flow rate (0,35 – 4000) m3/h is ± 0.31 %.
The general view of the facility is presented in Figure 1.
Test facility operates on the master meter principle. Ambient air is sucked by a fan and the flow rate is adjusted by regulation of the fan and electromotive valve. Testing procedure is controlled by software.
The calibration was performed at atmospheric conditions with air temperature of about 21°C. The absolute pressure was measured on the meters while the temperatures are measured downstream.
After reaching the stable flow rate, the single tests lasted minimum 180 seconds. Tests at each of the calibration flow rates were repeated several times (three or ten).
The error of the meter is calculated after correction of the volume indicated by master meter to the pressure and temperature conditions of the meter under test. The calibration was performed with one standard/master meter: Rotary gas meter G250.

Cesame Exadébit (LNE-LADG)



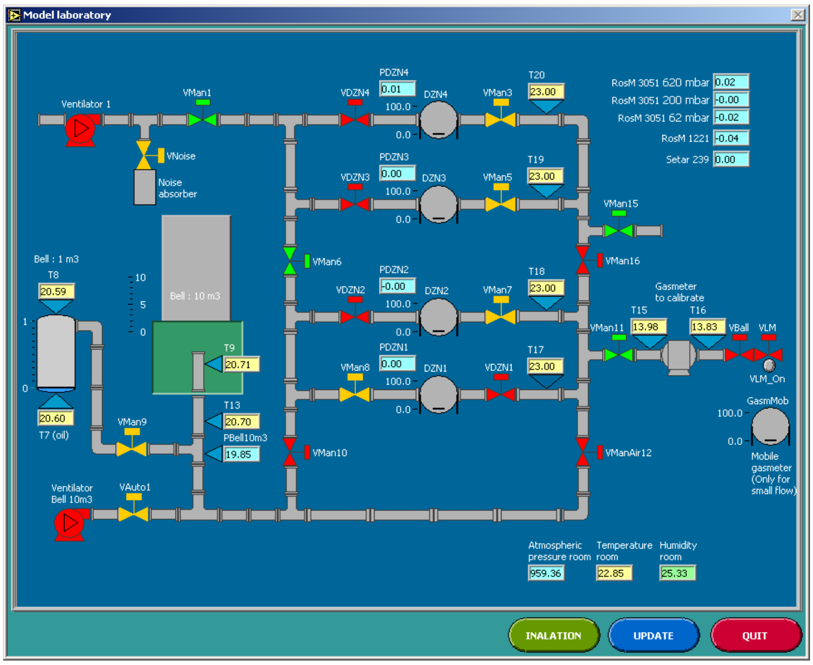
The meter under test is placed on a pipeline downstream from the set of nozzles. This configuration allows a comparison between the reference and tested device mass flows. The pressure and the temperature can be measured at the level of the meter under test in order to determine the volumetric flow rate going through.
The air coming from a storage vessel (200 bar, 110 m3) goes through the valves and the heating control system. This adjusts the suitable temperature and pressure upstream from the nozzles automatically. The pipelines bear the reference nozzles chosen according to the flow set points to be generated for the tests.

PTB, Germany



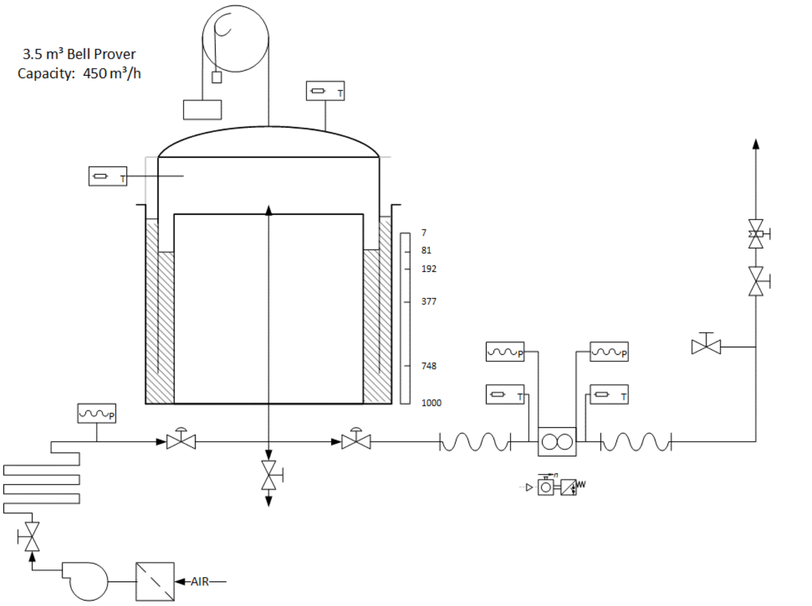
The large gas meter test bench works with critical nozzles as flow sensors. This principle exploits the property of a critical nozzle that the volume flow through the nozzle above a certain (critical) pressure ratio between input and output is only dependent on the speed of sound and the cross-sectional area in the nozzle neck. The flow resulting from the current temperature and inlet pressure ratios at the nozzles is converted to the thermodynamic conditions on the DUT and serves as a reference value for calibration.

METAS, Switzerland



Method used: conservation of mass, displacement of volume
Flying start method used

VSL the Netherlands



Method used: conservation of mass, bell prover / gas displacement per time
The Flying Start Finish method is used.

Annex 3. Calibration data

METAS

General		Facility temperatures and pressures				Reference values		IRM-3 DUO	
Test no.	Start time	T Upstream	T Downstream	P Upstream	P Downstream	Density Upstream	Flow rate	Flow rate	Error rate
[--]	[u:mm]	[°C]	[°C]	[mbar]	[mbar]	[kg/m³]	[m³/h]	[m³/h]	[%]
25 m³/h									
1.01	29-06-21 14:55	21.56		970.74	970.73	1.14	25.6712	25.63	-0.150
1.02	29-06-21 15:15	21.55		970.44	970.44	1.14	25.6761	25.64	-0.147
1.03	29-06-21 15:50	21.55		970.40	970.39	1.14	25.6784	25.65	-0.116
40 m³/h									
2.01	29-06-21 14:00	21.56		971.15	971.13	1.14	40.9143	40.91	-0.007
2.02	29-06-21 14:13	21.56		970.89	970.87	1.14	40.9317	40.91	-0.061
2.03	29-06-21 14:26	21.55		970.92	970.90	1.14	40.9333	40.91	-0.055
65 m³/h									
3.01	28-06-21 16:20	21.59		968.98	968.92	1.14	65.1362	65.14	0.007
3.02	28-06-21 16:34	21.59		969.02	968.96	1.14	65.1595	65.13	-0.044
3.03	29-06-21 09:05	21.59		969.25	969.19	1.14	65.1832	65.17	-0.016
3.04	29-06-21 09:19	21.59		969.21	969.15	1.14	65.1848	65.18	-0.009
3.05	29-06-21 09:29	21.58		969.06	969.00	1.14	65.1810	65.18	-0.006
3.06	29-06-21 09:41	21.58		968.94	968.88	1.14	65.1820	65.20	0.023
3.07	29-06-21 09:51	21.58		968.74	968.68	1.14	65.1994	65.20	-0.005
3.08	29-06-21 10:00	21.58		968.72	968.66	1.14	65.2105	65.19	-0.027
3.09	29-06-21 10:40	21.57		968.66	968.60	1.14	65.2035	65.20	-0.002
3.10	29-06-21 10:53	21.56		968.49	968.43	1.14	65.2050	65.22	0.022
100 m³/h									
4.01	28-06-21 15:50	21.59		969.35	969.22	1.14	99.9223	99.93	0.012
4.02	28-06-21 16:00	21.59		969.30	969.17	1.14	99.9561	99.92	-0.033
4.03	28-06-21 16:10	21.59		969.28	969.16	1.14	99.9542	99.93	-0.028
160 m³/h									
5.01	28-06-21 14:25	21.60		970.16	969.88	1.14	159.2406	159.22	-0.014
5.02	28-06-21 14:31	21.61		970.18	969.89	1.14	159.2452	159.27	0.018
5.03	28-06-21 14:38	21.61		970.15	969.87	1.14	159.2764	159.26	-0.010
5.04	28-06-21 14:45	21.61		970.09	969.81	1.14	159.2548	159.29	0.023
5.05	28-06-21 14:52	21.61		970.02	969.74	1.14	159.2743	159.26	-0.006
5.06		21.59		969.80	969.52	1.14	159.2569	159.29	0.020
5.07	28-06-21 15:12	21.61		969.67	969.39	1.14	159.2854	159.31	0.016
5.08	28-06-21 15:19	21.61		969.60	969.32	1.14	159.3545	159.31	-0.025
5.09	28-06-21 15:27	21.61		969.73	969.45	1.14	159.2999	159.31	0.004
5.10	28-06-21 15:33	21.61		969.62	969.34	1.14	159.3121	159.31	0.001
250 m³/h									
6.01	28-06-21 14:05	21.60		969.89	969.21	1.14	251.2159	251.15	-0.026
6.02	28-06-21 14:11	21.61		969.95	969.27	1.14	251.2521	251.13	-0.049
6.03	28-06-21 14:17	21.61		969.95	969.27	1.14	251.2487	251.20	-0.019
325 m³/h									
7.01	28-06-21 11:20	21.68		970.44	969.30	1.14	325.4626	325.36	-0.033
7.02	28-06-21 11:25	21.69		970.49	969.35	1.14	325.5322	325.38	-0.046
7.03	28-06-21 11:35	21.68		970.54	969.41	1.14	325.3729		-0.037
400 m³/h									
8.01		21.69		970.43	968.72	1.14	398.9159	398.66	-0.064
8.02		21.69		970.20	968.49	1.14	399.1292	398.90	-0.059
8.03		21.69		970.15	968.45	1.14	399.1207	398.98	-0.036
8.04		21.69		970.19	968.48	1.14	399.2021	398.97	-0.058
8.05		21.69		970.17	968.47	1.14	399.1366	399.03	-0.028
8.06		21.69		970.14	968.43	1.14	399.1714	398.98	-0.048
8.07		21.70		970.14	968.44	1.14	399.1537	398.90	-0.062
8.08		21.69		970.12	968.43	1.14	399.1979	399.03	-0.042
8.09		21.69		970.14	968.44	1.14	399.1149	398.95	-0.040
8.10		21.69		970.14	968.44	1.14	399.1153	398.95	-0.040

PTB

25 m³/h									
General		Facility temperatures and pressures				Reference values		IRM-3 DUO	
Test no. [--]	Start time [u:mm]	T Upstream [°C]	T Downstream [°C]	P Upstream [Pa(g)]	P Downstream [Pa(g)]	Density Upstream [kg/m³]	Flow rate [m³/h]	Flow rate [m³/h]	Error rate [%]
1.01	12:58	21.98	21.98	1014.74	1014.70	1.19	25.7000	25.67	-0.122
1.02	13:00	21.99	21.99	1014.74	1014.70	1.19	25.7004	25.67	-0.122
1.03	13:03	22.00	22.00	1014.70	1014.66	1.19	25.7010	25.67	-0.126
40 m³/h									
2.01	13:09	22.04	22.02	1014.62	1014.57	1.19	41.1850	41.17	-0.038
2.02	13:11	22.01	22.01	1014.58	1014.53	1.19	41.1819	41.17	-0.033
2.03	13:14	22.01	22.01	1014.56	1014.51	1.19	41.1812	41.17	-0.029
65 m³/h									
3.01	13:19	22.00	22.01	1014.55	1014.46	1.19	66.9596	66.99	0.050
3.02	13:22	21.99	22.00	1014.57	1014.48	1.19	66.9589	66.99	0.049
3.03	13:24	21.98	22.00	1014.58	1014.49	1.19	66.9568	66.99	0.048
3.04	13:27	21.96	21.99	1014.58	1014.50	1.19	66.9547	66.99	0.049
3.05	13:29	21.95	21.98	1014.60	1014.51	1.19	66.9530	66.99	0.049
3.06	13:32	21.95	21.98	1014.58	1014.49	1.19	66.9536	66.99	0.050
3.07	13:34	21.94	21.98	1014.58	1014.50	1.19	66.9520	66.99	0.051
3.08	13:37	21.94	21.98	1014.57	1014.48	1.19	66.9522	66.99	0.053
3.09	13:39	21.94	21.97	1014.57	1014.48	1.19	66.9516	66.98	0.050
3.10	13:42	21.93	21.97	1014.56	1014.48	1.19	66.9503	66.98	0.050
100 m³/h									
4.01	13:51	21.92	21.96	1014.56	1014.40	1.19	103.6903	103.76	0.064
4.02	13:54	21.93	21.97	1014.52	1014.37	1.19	103.6945	103.76	0.064
4.03	13:57	21.93	21.97	1014.50	1014.34	1.19	103.6943	103.76	0.061
160 m³/h									
5.01	14:04	21.93	21.97	1014.34	1014.00	1.19	165.4119	165.55	0.083
5.02	14:07	21.95	21.98	1014.36	1014.01	1.19	165.4189	165.56	0.084
5.03	14:09	21.96	21.98	1014.36	1014.02	1.19	165.4202	165.56	0.084
5.04	14:12	21.96	21.99	1014.32	1013.98	1.19	165.4189	165.56	0.086
5.05	14:14	21.97	21.99	1014.28	1013.94	1.19	165.4220	165.56	0.086
5.06	14:17	21.98	22.00	1014.23	1013.89	1.19	165.4279	165.57	0.085
5.07	14:19	21.97	22.00	1014.21	1013.87	1.19	165.4219	165.57	0.087
5.08	14:22	21.97	22.00	1014.24	1013.89	1.19	165.4224	165.57	0.087
5.09	14:24	21.98	22.00	1014.24	1013.90	1.19	165.4274	165.57	0.085
5.10	14:27	21.98	22.00	1014.24	1013.90	1.19	165.4268	165.57	0.087
250 m³/h									
6.01	14:40	21.97	22.00	1013.92	1013.16	1.19	256.5736	256.56	-0.006
6.02	14:43	21.98	22.00	1013.93	1013.17	1.19	256.5847	256.56	-0.008
6.03	14:45	21.98	22.00	1013.94	1013.18	1.19	256.5841	256.56	-0.009
325 m³/h									
7.01	15:02	21.99	22.01	1013.65	1012.41	1.19	333.4787	333.37	-0.033
7.02	15:04	21.99	22.01	1013.63	1012.38	1.19	333.4772	333.37	-0.031
7.03	15:07	22.00	22.01	1013.61	1012.37	1.19	333.4766	333.38	-0.030
400 m³/h									
8.01	15:26	21.97	21.99	1013.20	1011.30	1.18	410.9889	411.09	0.025
8.02	15:28	22.00	22.00	1013.23	1011.33	1.18	410.9986	411.11	0.028
8.03	15:30	22.00	22.01	1013.24	1011.34	1.18	411.0047	411.12	0.027
8.04	15:33	22.00	22.01	1013.22	1011.32	1.18	411.0036	411.11	0.027
8.05	15:36	22.00	22.01	1013.22	1011.31	1.18	411.0044	411.12	0.028
8.06	15:39	22.00	22.01	1013.19	1011.29	1.18	411.0048	411.12	0.028
8.07	15:42	22.00	22.01	1013.19	1011.29	1.18	411.0190	411.12	0.025
8.08	15:45	22.00	22.01	1013.18	1011.28	1.18	411.0062	411.12	0.027
8.09	15:47	22.00	22.01	1013.18	1011.28	1.18	411.0047	411.12	0.028
8.10	15:50	21.99	22.00	1013.17	1011.27	1.18	411.0071	411.11	0.025

VSL

25 m³/h									
General		Facility temperatures and pressures				Reference values		IRM-3 DUO	
Test no. [--]	Start time [u:mm]	T Upstream [°C]	T Downstream [°C]	P Upstream [Pa(g)]	P Downstream [Pa(g)]	Density Upstream [kg/m³]	Flow rate [m³/h]	Flow rate [m³/h]	Error rate [%]
1.01	14:30	20.15		2430.5	2181.2		25.126	25.08	-0.175
1.02	14:33	20.15		2430.5	2185.4		25.124	25.08	-0.166
1.03	14:36	20.15		2430.5	2191.3		25.124	25.08	-0.177
40 m³/h									
2.01	15:02	20.16		2426.1	2222.6		39.931	39.906	-0.063
2.02	15:05	20.16		2426.2	2227.6		39.923	39.902	-0.052
2.03	15:07	20.16		2425.7	2230.2		39.928	39.902	-0.066
65 m³/h									
3.01	15:15	20.17		2414.1	2236.4		65.461	65.483	0.03
3.02	15:19	20.17		2414.4	2235.4		65.460	65.490	0.05
3.03	15:22	20.18		2414.1	2237.8		65.468	65.492	0.04
3.04	15:25	20.18		2414.4	2240.2		65.465	65.489	0.04
3.05	15:27	20.19		2414.3	2246.4		65.447	65.477	0.05
3.06									
3.07									
3.08									
3.09									
3.10									
100 m³/h									
4.01	15:44	20.21		2389.6	2244.2		100.415	100.464	0.05
4.02	15:46	20.22		2389.9	2243.9		100.427	100.490	0.06
4.03	15:48	20.22		2389.9	2244.3		100.446	100.500	0.05
160 m³/h									
5.01	15:55	20.25		2327.1	2225.1		160.618	160.686	0.04
5.02	16:01	20.26		2326.6	2225.1		160.777	160.858	0.05
5.03	16:05	20.27		2326.5	2233.4		160.813	160.879	0.04
5.04	16:07	20.27		2325.7	2228.7		160.859	160.908	0.03
5.05	16:13	20.28		2325.1	2234.2		160.923	160.980	0.04
5.06	16:14	20.29		2325.4	2234.4		160.914	160.966	0.03
5.07	16:16	20.29		2326.5	2234.7		160.950	161.002	0.03
5.08	17:01	20.18		2326.7	2260.9		161.016	161.067	0.03
5.09	17:03	20.19		2326.0	2262.4		160.961	161.016	0.03
5.10	17:05	20.20		2327.1	2263.5		160.988	161.059	0.04
250 m³/h									
6.01	17:16	20.22		2180.8	2212.9		251.968	252.044	0.03
6.02	17:19	20.24		2179.8	2214.9		252.111	252.154	0.02
6.03	17:20	20.24		2180.4	2217.6		252.231	252.326	0.04
325 m³/h									
7.01	17:28	20.24		2016.3	2147.0		327.030	327.020	-0.003
7.02	17:31	20.25		2024.3	2153.5		326.448	326.450	0.001
7.03	17:34	20.26		2021.6	2149.2		326.566	326.576	0.003
400 m³/h									
8.01	16:49	20.05		1829.8	1819.3		402.27	402.05	-0.06
8.02	16:54	20.09		1817.7	1820.6		401.74	401.44	-0.07
8.03	16:55	20.09		1854.7	1865.0		402.34	402.29	-0.01
8.04	17:00	20.12		1827.7	1842.6		402.15	401.96	-0.05
8.05	17:01	20.12		1852.4	1874.9		402.03	401.96	-0.02
8.06	17:05	20.16		1823.2	1856.5		402.22	402.00	-0.05
8.07	17:07	20.15		1840.3	1890.9		401.95	401.87	-0.02
8.08	17:11	20.18		1819.6	1867.1		402.63	402.38	-0.06
8.09	17:12	20.19		1853.6	1903.5		402.22	402.11	-0.03
8.10	17:15	20.17		1819.8	1866.7		402.27	402.11	-0.04

LNE-LADG

25 m³/h									
General		Facility temperatures and pressures				Reference values		IRM-3 DUO	
Test no. [--]	Start time [u:mm]	T Upstream [°C]	T Downstream [°C]	P Upstream [bar(g)]	P Downstream [bar(g)]	Density Upstream [kg/m^3]	Flow rate [m³/h]	Flow rate [m³/h]	Error rate [%]
1.01	14:44	21.23	21.25	1.01	1.01	1.20	24.7320	24.74	0.037
1.02	14:45	21.24	21.26	1.01	1.01	1.20	24.7332	24.74	0.031
1.03	14:47	21.24	21.27	1.01	1.01	1.20	24.7319	24.74	0.030
40 m³/h									
2.01	14:28	21.20	21.18	1.01	1.01	1.20	39.6086	39.62	0.039
2.02	14:30	21.20	21.17	1.01	1.01	1.20	39.6185	39.63	0.035
2.03	14:31	21.20	21.16	1.01	1.01	1.20	39.6204	39.64	0.043
65 m³/h									
3.01	14:13	21.07	20.94	1.01	1.01	1.20	64.5182	64.61	0.147
3.02	14:14	21.07	20.93	1.01	1.01	1.20	64.5163	64.61	0.153
3.03	14:15	21.07	20.94	1.01	1.01	1.20	64.5123	64.61	0.148
3.04	14:16	21.07	20.93	1.01	1.01	1.20	64.5047	64.61	0.159
3.05	14:17	21.06	20.92	1.01	1.01	1.20	64.5051	64.61	0.161
3.06	14:19	21.06	20.93	1.01	1.01	1.20	64.5035	64.61	0.158
3.07	14:20	21.06	20.92	1.01	1.01	1.20	64.4998	64.61	0.166
3.08	14:21	21.05	20.92	1.01	1.01	1.20	64.4953	64.60	0.167
3.09	14:22	21.05	20.92	1.01	1.01	1.20	64.4946	64.61	0.175
3.10	14:23	21.05	20.91	1.01	1.01	1.20	64.4906	64.60	0.174
100 m³/h									
4.01	14:06	21.10	20.98	1.01	1.01	1.20	99.4933	99.62	0.124
4.02	14:07	21.09	20.97	1.01	1.01	1.20	99.4991	99.62	0.124
4.03	14:08	21.09	20.96	1.01	1.01	1.20	99.5066	99.63	0.125
160 m³/h									
5.01	13:54	21.03	20.87	1.01	1.01	1.20	159.1464	159.21	0.042
5.02	13:55	21.01	20.85	1.01	1.01	1.20	159.1516	159.23	0.051
5.03	13:56	21.00	20.83	1.01	1.01	1.20	159.1667	159.24	0.045
5.04	13:56	20.96	20.81	1.01	1.01	1.20	159.1797	159.25	0.045
5.05	13:57	20.98	20.79	1.01	1.01	1.20	159.1692	159.26	0.055
5.06	13:57	20.92	20.78	1.01	1.01	1.20	159.1826	159.26	0.047
5.07	13:58	20.95	20.76	1.01	1.01	1.20	159.1884	159.29	0.063
5.08	13:59	20.94	20.75	1.01	1.01	1.20	159.1912	159.28	0.055
5.09	13:59	20.93	20.73	1.01	1.01	1.20	159.1979	159.30	0.063
5.10	14:00	20.99	20.72	1.01	1.01	1.20	159.1755	159.29	0.072
250 m³/h									
6.01	13:49	20.83	20.56	1.01	1.01	1.20	246.7253	246.66	-0.024
6.02	13:49	20.81	20.55	1.01	1.01	1.20	246.6313	246.58	-0.022
6.03	13:50	20.80	20.53	1.01	1.01	1.20	246.6421	246.56	-0.033
325 m³/h									
7.01	13:45	20.98	20.83	1.01	1.01	1.20	322.4844	322.04	-0.137
7.02	13:45	21.02	20.78	1.01	1.01	1.20	322.5117	322.03	-0.149
7.03	13:45	21.06	20.73	1.01	1.01	1.20	322.4627	322.02	-0.137
400 m³/h									
8.01	13:38	21.62	21.64	1.01	1.01	1.19	397.9422	397.09	-0.214
8.02	13:38	21.57	21.58	1.01	1.01	1.19	397.9894	397.14	-0.214
8.03	13:39	21.71	21.52	1.01	1.01	1.19	397.9404	397.12	-0.206
8.04	13:39	21.49	21.47	1.01	1.01	1.19	397.9894	397.16	-0.208
8.05	13:39	21.53	21.41	1.01	1.01	1.19	398.0479	397.22	-0.208
8.06	13:40	21.66	21.35	1.01	1.01	1.19	397.9679	397.15	-0.205
8.07	13:40	21.44	21.29	1.01	1.01	1.19	398.1789	397.37	-0.203
8.08	13:40	21.35	21.24	1.01	1.01	1.19	398.0793	397.28	-0.201
8.09	13:41	21.40	21.18	1.01	1.01	1.19	398.0752	397.28	-0.199
8.10	13:41	21.31	21.12	1.01	1.01	1.20	398.0809	397.32	-0.192

LABSAGAS

General		Facility temperatures and pressures				Reference values		IRM-3 DUO	
Test no. [--]	Start time [u:mm]	T Upstream [°C]	T Downstream [°C]	P Upstream [bar(g)]	P Downstream [bar(g)]	Density Upstream [kg/m^3]	Flow rate [m³/h]	Flow rate [m³/h]	Error rate [%]
25 m³/h									
1.01	09:45	21.22	21.28	0.96	0.96	1.13	25.0426	24.99	-0.182
1.02	09:48	21.26	21.31	0.96	0.96	1.13	25.0603	25.01	-0.184
1.03	09:51	21.27	21.32	0.96	0.96	1.13	25.1018	25.05	-0.185
40 m³/h									
2.01	09:58	21.08	21.15	956.31	956.40	1.13	40.4525	40.40	-0.123
2.02	10:01	21.10	21.17	956.30	956.39	1.13	40.4150	40.37	-0.116
2.03	10:04	21.12	21.20	956.25	956.34	1.13	40.3901	40.33	-0.121
65 m³/h									
3.01	10:13	21.02	21.09	0.96	0.96	1.13	65.1570	65.13	-0.029
3.02	10:16	21.04	21.12	0.96	0.96	1.13	65.0596	65.04	-0.034
3.03	10:19	21.04	21.11	0.96	0.96	1.13	65.0162	64.99	-0.035
3.04	10:22	21.05	21.11	0.96	0.96	1.13	65.0805	65.05	-0.038
3.05	10:25	21.04	21.10	0.96	0.96	1.13	65.0960	65.08	-0.038
3.06	10:28	21.06	21.13	0.96	0.96	1.13	65.1395	65.12	-0.031
3.07	10:31	21.05	21.11	0.96	0.96	1.13	65.0956	65.06	-0.041
3.08	10:34	21.06	21.12	0.96	0.96	1.13	65.0399	65.01	-0.034
3.09	10:37	21.06	21.12	0.96	0.96	1.13	65.0358	65.00	-0.044
3.10	10:40	21.06	21.13	0.96	0.96	1.13	65.0407	65.02	-0.043
100 m³/h									
4.01	10:50	20.98	21.05	0.96	0.96	1.13	100.1613	100.12	-0.043
4.02	10:53	20.99	21.07	0.96	0.96	1.13	100.0459	100.01	-0.036
4.03	10:56	20.99	21.07	0.96	0.96	1.13	100.1306	100.10	-0.040
160 m³/h									
5.01	11:05	20.93	21.00	0.95	0.96	1.13	160.6689	160.68	0.003
5.02	11:08	20.92	20.97	0.95	0.96	1.13	160.5666	160.56	-0.003
5.03	11:11	20.91	20.95	0.95	0.96	1.13	160.6356	160.63	-0.005
5.04	11:14	20.90	20.93	0.95	0.96	1.13	160.7162	160.70	-0.006
5.05	11:17	20.89	20.92	0.95	0.96	1.13	160.7196	160.72	-0.004
5.06	11:20	20.88	20.92	0.95	0.96	1.13	160.4993	160.51	0.001
5.07	11:23	20.88	20.93	0.95	0.96	1.13	160.3940	160.40	0.000
5.08	11:26	20.88	20.93	0.95	0.96	1.13	160.4681	160.51	0.006
5.09	11:29	20.90	20.96	0.95	0.96	1.13	160.3222	160.33	0.006
5.10	11:32	20.91	20.96	0.95	0.96	1.13	160.4607	160.48	0.009
250 m³/h									
6.01	11:45	20.93	21.03	0.95	0.96	1.13	250.5036	250.46	-0.019
6.02	11:48	20.94	21.03	0.95	0.96	1.13	250.6097	250.56	-0.020
6.03	11:51	20.93	21.02	0.95	0.96	1.13	250.5278	250.47	-0.024
325 m³/h									
7.01	12:05	20.85	20.95	0.95	0.96	1.13	325.8894	325.67	-0.067
7.02	12:08	20.88	20.97	0.95	0.96	1.13	325.7838	325.57	-0.069
7.03	12:11	20.88	20.97	0.95	0.96	1.13	326.0247	325.80	-0.068
400 m³/h									
8.01	12:20	20.76	20.85	0.95	0.96	1.12	400.0568	399.73	-0.082
8.02	12:23	20.78	20.87	0.95	0.96	1.12	399.6087	399.31	-0.077
8.03	12:26	20.78	20.86	0.95	0.96	1.12	399.2131	398.85	-0.090
8.04	12:29	20.77	20.85	0.95	0.96	1.12	399.5609	399.20	-0.092
8.05	12:32	20.80	20.91	0.95	0.96	1.12	399.7682	399.44	-0.083
8.06	12:35	20.82	20.93	0.95	0.96	1.12	399.6942	399.33	-0.090
8.07	12:38	20.82	20.93	0.95	0.96	1.12	399.2607	398.89	-0.093
8.08	12:41	20.85	20.99	0.95	0.96	1.12	399.3913	399.06	-0.083
8.09	12:44	20.88	21.01	0.95	0.96	1.12	399.4295	399.08	-0.090
8.10	12:47	20.82	20.93	0.95	0.96	1.12	399.1224	398.77	-0.092