SIM.M.FF-K6.2017

SIM key comparison
Low-Pressure Gas Flow, 2 m^3/h to 100 m^3/h

Final Report

Pilot
GERVACIO SANCHEZ, Juan Carlos – CENAM, Mexico
ARIAS ROMERO, Roberto – CENAM, Mexico
OCHOA DIAZ, Carlos – CENAM, Mexico

Co-Pilot
FORASTIERI, Juan – INTI, Argentina
LUPO, Sergio – INTI, Argentina
BRENTA, Hernán – INTI, Argentina

Participants
MENDOZA AGUIRRE, Juan José - IBMETRO, Bolivia
OCHOA QUIQUIA, Carlos Roberto – INACAL, Perú
WRIGHT, John – NIST, USA
LACHANCE, Christian – MC, Canada
ABRIL BLANCO, Henry – CDT de GAS, Colombia

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Abstract

The SIM.M.FF-K6.2017 comparison was organised for the purpose of the determination of the degree of equivalence (E_n) of the laboratory standards for low-pressure gas flow measurement over the range from 2 m^3/h to 100 m^3/h. A rotary gas meter G65, donated by PTB/Germany to INTI/Argentina, within the framework of the 'Triangular Cooperation in Natural Gas Metrology in Latin America' project, was used as a transfer standard. Seven laboratories participated between November 2017 and August 2018: CENAM (Mexico), INTI (Argentina), IBMETRO (Bolivia), INACAL (Perú), NIST (USA), MC (Canada), and CDT (Colombia). CENAM (Mexico) was selected as the PILOT laboratory with the support of INTI (Argentina) as CO-PILOT. This comparison is linked to CCM.FF-K6.2011. Two participants (CENAM and NIST) provide linkage to the Key Comparison Reference Value (KCRV) of CCM.FF-K6.2011 comparison. Five participants reported independent traceability chains to the SI, two of them (INACAL and IBMETRO) are traceable to CENAM. The measurements were provided at prescribed reference pressure and temperature conditions. The KCRV of CCM.FF-K6.2011 comparison and all results were used in the determination of the Regional Comparison Reference Value (RCRV) and its uncertainty. The reference value was determined at each flow separately using as guidance the "procedure A" presented by M. G. Cox(*). The degree of equivalence with the RCRV was calculated for each flow and laboratory. All reported results were consistent with the reference value, E_n values were less than one for all participants in every flow tested.

Graphical Summary of Results

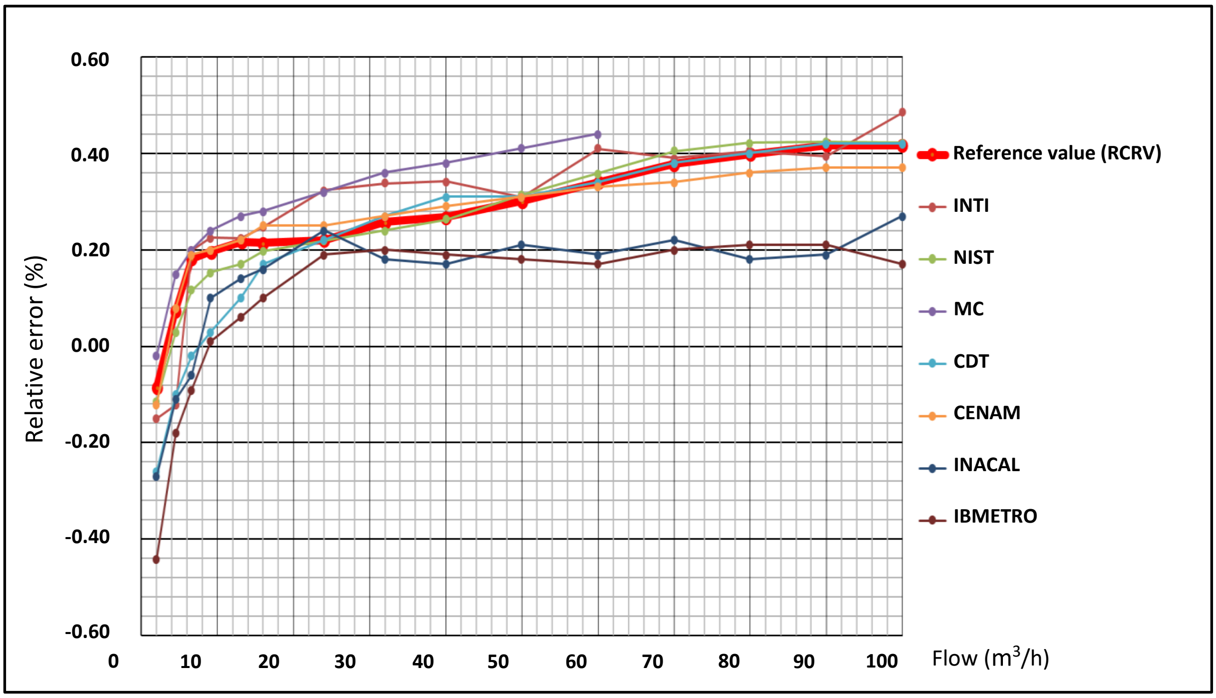


Figure 1: RCRV and each participant error curve

Results by participant, including a graphical representation of the relative error and the expanded uncertainty of measurement, are shown in Appendix B.

(*) Cox M.G., Evaluation of key comparison data. Metrologia, 2002, 39, 589-595.

Contents

1. Introduction

Between 2013 and 2015 a preliminary exercise took place in the region, a pilot study was conducted by CENAM, where all participants of SIM.M.FF-K6.2017 (except IBMETRO) participated. The transfer standard used was a rotary piston G65 flowmeter. Information of the pilot study was published at CENAM's 2016 Metrology Symposium(*).

Flows used in the SIM Key Comparison SIM.M.FF-K6.2017 were selected to be consistent with the mentioned pilot study and the CCM.FF-K6.2011 comparison.

(*) Simposio de Metrología 2016. ESTUDIO PILOTO PARA LA CALIBRACIÓN DE MEDIDORES DE FLUJO DE GAS EN PAÍSES MIEMBROS DEL SIM. Juan Carlos Gervacio, Roberto Arias Romero, John Wright, Henry Abril, Carlos Ochoa, Sergio Lupo. 19 al 23 de septiembre de 2016.

2. List of Participants, facilities used, circulation scheme

Seven laboratories participated between November 2017 and June 2020. The list of participants, a summary of the facilities and the circulation scheme are presented below.

2.1. List of participants

- CENAM: Centro Nacional de Metrología, MEXICO.
- INTI: Instituto Nacional de Tecnología Industrial, ARGENTINA.
- IBMETRO: Instituto Boliviano de Metrología, BOLIVIA.
- INACAL: Instituto Nacional de Calidad, PERU.
- NIST: National Institute of Standards and Technology, UNITED STATES OF AMERICA.
- MC(**): Gas Measurement, Measurement Canada. Innovation, Science and Economic Development Canada / Government of Canada, CANADA.
- CDT(**): Corporación Centro de Desarrollo Tecnológico del Gas, COLOMBIA.

(**) Not signatories of the BIPM CIPM-MRA.

2.2. Facilities used

Each laboratory described the equipment used in the calibration and sent information about their measurement traceability. The following table shows a summary of the facilities used. Details can be found in Appendix A

Participant	Type of reference standard	Reference standard uncertainty (k=2, %)	Date of test	Independent traceability?
CENAM (Mexico)	Bell prover	0.13 – 0.14	May. 2018 and Aug. 2018	Yes
INTI (Argentina)	Bell prover	0.18	Nov. 2017 and Jun. 2020	Yes
IBMETRO (Bolivia)	Rotary piston meters	0.35 – 0.36	Sep.2019	No
INACAL (Perú)	Rotary piston meters	0.25 – 0.34	Feb. 2019	No
NIST (United States)	CFV	0.104	Jul. 2018	Yes
MC (Canada)	Bell prover	0.20	Sep. 2018	Yes
CDT (Colombia)	Bell Prover	0.18 – 0.21	Nov.2018	Yes
	Rotary piston meters			Yes(*)

Table 1. Participant's facilities and other related information.

(*) For the rotary piston meters the traceability is independent to the other comparison participants.

2.3. Circulation scheme

The circulation scheme was a single loop, with repetition of the pilot and the co-pilot measurements, conveniently placed to assess the transfer standard stability. The transfer standard was measured two times by INTI, at the beginning and end of the comparison. CENAM also measured two times during the comparison.

Each laboratory had a time interval for providing the measurements results and for sending the transfer standard to the next laboratory. Due to logistics problems the transfer standard shipment was delayed several times. Time schedule is shown below.

Country	Participant	Date of test
Argentina	INTI (Co-pilot)	November, 2017
Mexico	CENAM (Pilot)	May, 2018
Canada	MC	September, 2018
USA	NIST	July, 2018
Mexico	CENAM (Pilot)	August, 2018
Colombia	CDT	November, 2018
Perú	INACAL	February, 2019
Bolivia	IBMETRO	September, 2019
Argentina	INTI (Co-pilot)	June, 2020

Table 2. Dates of tests.

3. Transfer Standard

The transfer standard was a rotary gas meter, model S Delta Flow meter inside the body Itron. The meter, a pulse transmitter board and a filter were shipped in one box. The transfer standard is property of INTI.

Technical data	Detail
Type of meter	Rotary gas meter
Manufacturer / model:	ITRON / Delta S-Flow
Size:	G65
Serial number:	3401992332
Inside nominal diameter:	DN 50
Q_{MAX}:	100 m^3/h
p_{MAX} :	16 bar
Q_{MIN}:	0.8 m^3/h
K-factor	20 646.5 imp/m^3

Table 3. Transfer standard technical details.

Figure 2: TS up to 100 m^3/h

4. Comparison Protocol

The tested flows were in the measuring range from 2 m^3/h to 100 m^3/h. Participating laboratories used their usual calibration procedure but following the instructions below:

- The measuring method was by direct comparison between transfer standard and the metrological best gas flow reference standard of the participant laboratory.
- The transfer standard was handled in accordance with the recommendations given by the manufacturer, following the laboratory procedure for safe handling of gas meters.
- The transfer standard was stored in the laboratory at least 24 hours before starting the calibration, at the laboratory‘s temperature. This temperature was 20 ºC ± 5 ºC.
- The transfer standard was lubricated as specified by the manufacturer.
- Calibration medium was air and its temperature was taken as the laboratory‘s ambient temperature.
- The transfer standard was tested in horizontal position, using air near barometric pressure.
- The transfer standard test temperature (t_M) was measured upstream of the meter.
- The transfer standard test pressure (p_M) was measured at the pressure tap located at the outlet of the meter.
- The transfer standard differential pressure (Δp) was measured at both pressure taps located at inlet and outlet of the meter.

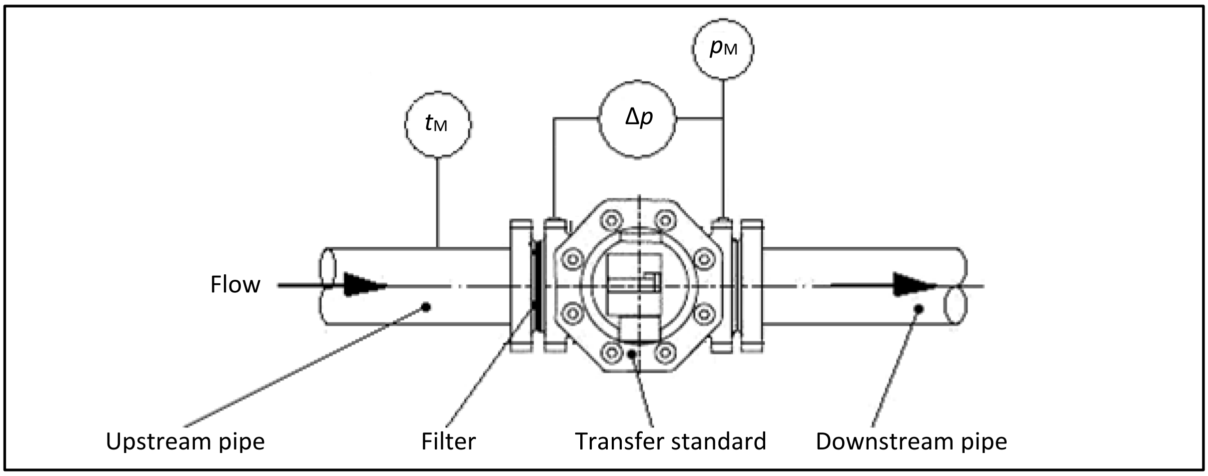


Figure 3: Transfer standard installation.

- Before starting the calibration, the transfer standard worked at least 15 or 20 minutes at 0.70 Q_{MAX}, to reach thermal equilibrium.
- The transfer standard was tested in 15 points of flow: 2 m^3/h; 4.5 m^3/h; 6.6 m^3/h; 9.1 m^3/h; 13.1 m^3/h; 16 m^3/h; 24 m^3/h; 32 m^3/h; 40 m^3/h; 50 m^3/h; 60 m^3/h; 70 m^3/h; 80 m^3/h; 90 m^3/h and 100 m^3/h. Flow was within ±3 % of the required value. Laboratories which cannot achieve all these prescribed testing points performed the tests in the points available at the laboratory, from the fifteen points mentioned above.
- A pulse transmitter board provided with the TS was used for the tests.
- Each participant recorded the results of: The transfer standard test temperature (t_M), pressure (p_M), differential pressure (Δp), and error of measurement, for all test flows.
- The test in each flow was repeated at least 3 times and then the mean was calculated, for each flow. The flow deviation was within the interval of ± 3 % from the required value.
- The interval of each test was (minimum) one minute. Beforehand the flow was accurately stabilized.
- The error of measurement was calculated using the following formula:

$$e/\% = \frac{V_T - V_S}{V_S}.100 \qquad (4.1)$$

e: Error of measurement

V_T: Indicated volume by the transfer standard (m^3)

V_S: Reference volume, obtained from the primary standard of gas flow of the laboratory (m^3)

5. Methods of Measurement and Range of Conditions

The conditions measured during tests were provided by all participants. Values are shown below.

Participant	CENAM (ºC)	INTI (ºC)	IBMETRO (ºC)	INACAL (ºC)	NIST (ºC)	MC (ºC)	CDT (ºC)
Max.	20.80	20.50	17.53	23.70	25.31	20.62	20.35
Min.	19.10	20.00	16.50	22.90	23.10	20.48	20.10
Max.-Min.	1.70	0.50	1.03	0.80	2.21	0.14	0.25
Mean	19.95	20.25	17.02	23.30	24.20	20.55	20.22

Table 4. Temperature (°C) conditions during tests, by participant.

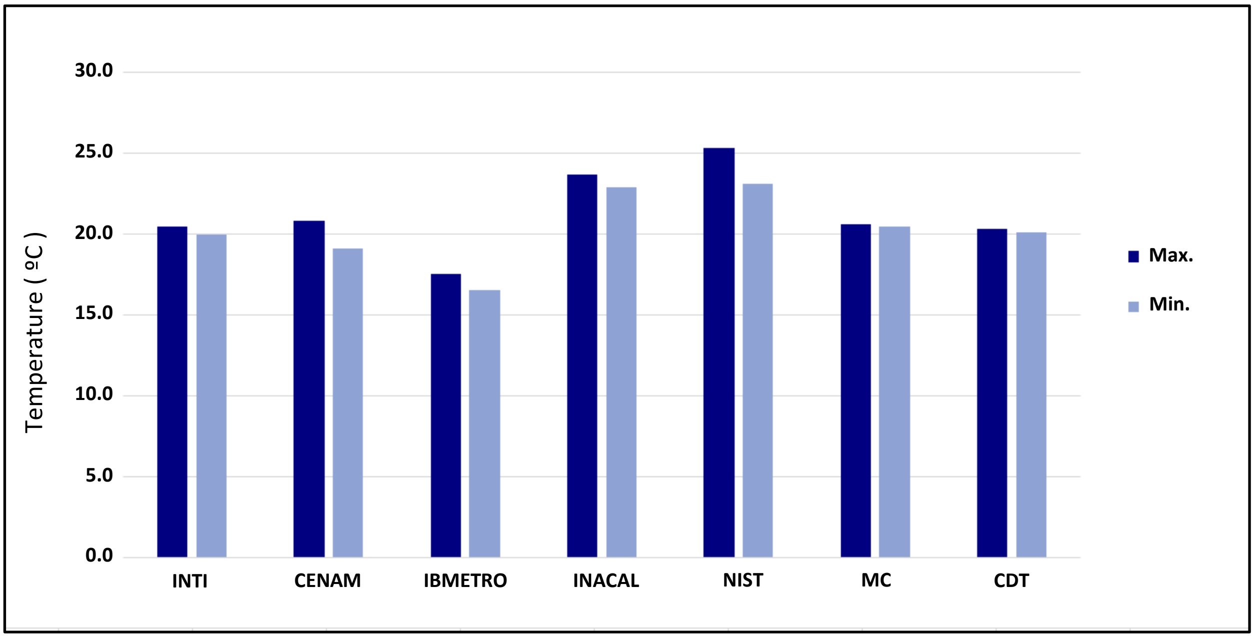


Figure 4. Graphical representation of the temperature conditions during tests.

6. Uncertainty due to the Transfer Standard

The standard uncertainties of the error in each laboratory u_{x_1}, u_{x_2} .... u_{x_n} includes the uncertainty of the transfer standard, and was calculated using the following formula:

$$u_{d_i} = \sqrt{\left(\frac{U_{x_i}}{2}\right)^2 + u_{TS}{}^2} \quad (6.1)$$

U_{x_i}: Expanded uncertainty informed by each participant

u_{TS}: Estimated standard uncertainty caused by the stability and temperature sensitivity of the transfer standard

The transfer standard was measured two times by INTI, at the beginning and end of the comparison. CENAM also measured two times during the comparison. Values are shown below:

Flow (m^3/h)	INTI 1 (%)	INTI 2 (%)	Diff. INTI, Δe (%)	CENAM 1 (%)	CENAM 2 (%)	Diff. CENAM, Δe (%)
2	-0.15	-0.11	0.04	-0.12	-0.15	0.03
4.5	-0.12	-0.15	-0.03	0.08	0.09	0.01
6.6	0.20	0.16	-0.04	0.19	0.17	0.02
9.1	0.23	0.22	-0.01	0.20	0.21	0.01
13.1	0.22	0.15	-0.07	0.22	0.22	0.00
16	0.25	0.17	-0.08	0.25	0.24	0.01
24	0.32	0.29	-0.03	0.25	0.25	0.00
32	0.34	0.31	-0.03	0.27	0.27	0.00
40	0.34	0.34	0.00	0.29	0.30	0.01
50	0.31	0.32	0.01	0.31	0.32	0.01
60	0.41	0.34	-0.07	0.33	0.35	0.02
70	0.39	0.40	0.01	0.34	0.34	0.00
80	0.40	0.41	0.01	0.36	0.35	0.01
90	0.39	0.42	0.03	0.37	0.36	0.01
100	0.48	0.42	-0.06	0.37	0.38	0.01

Table 5. Relative error of the TS, obtained at INTI and CENAM.

The transfer standard stability was determined based on these results. A maximum change in the error Δe_{MAX} = 0.08 % was found during these measurements.

The minimum and maximum temperature values in the laboratories were in the range (16.50 to 25.31) °C (see Table 4). The temperature sensitivity of the transfer standard in the Comparison was not tested, it was assumed a value for temperature sensitivity $u_T = 0.03\%$, as it was considered in CIPM key comparison CCM.FF-K6.2011 report. No temperature corrections were made to the data submitted by participants. The temperature sensitivity was treated as a transfer standard uncertainty component with a rectangular probability distribution (0.03 % ⁄ 2√3).

Combining the uncertainties due to transfer standard calibration stability and temperature sensitivity by root-sum-of-squares leads to a transfer standard uncertainty of 0.09 %.

$$u_{TS} = \sqrt{\left(\frac{\Delta e_{MAX}}{2\sqrt{3}}\right)^2 + \left(\frac{u_T}{2\sqrt{3}}\right)^2} \qquad (6.2)$$

This transfer standard uncertainty component was combined by root-sum-of-squares with the standard uncertainty provided by each participating laboratory (Equation 6.1) and the results are presented in annex B.

7. Corrections to the Transfer Standard

All participants measured the actual volumetric flow at the transfer standard based on the pressure and temperature measurements made at the transfer standard (see Figure 2). No further pressure corrections to the data submitted were necessary.

The tolerance of the flow during measurements was specified in the comparison protocol to be within 3 %. No correction was made for flows not meeting the 3 % criteria.

8. Data Processing and Computation of the RCRV

The reference value was determined at each flow separately. All laboratories reported independent traceability chains to other members of the comparison, except IBMETRO and INACAL with traceability to CENAM.

NIST and CENAM acted as linkage laboratories, as they represented SIM at the CIPM key comparison CCM.FF-K6.2011. Then the Regional Comparison Reference Value (RCRV) for each flow was obtained from the values informed by these two laboratories.

Determination of the Regional Comparison Reference Value (RCRV) and its uncertainty

The reference value was calculated as weighted mean error (WME) from CENAM and NIST values, as detailed below:

$$RCRV = MVLK(RC) + RCC \tag{8.1}$$

$RCRV$: Regional Comparison Reference Value

$MVLK(RC)$: Weighted Mean Value between Linkage Laboratories, at the Regional Comparison

RCC: Regional Comparison Correction

$$RCC = KCRV - MVLK(KC) \tag{8.2}$$

$KCRV$: Key Comparison Reference Value, from CCM.FF-K6.2011

$MVLK(KC)$: Weighted Mean Value between Linkage Laboratories, at the Key Comparison

The range of values for the Regional Comparison Correction was -0.012 % to 0.036 % (see Table 8).

$$MVLK(KC) = \frac{\frac{z_1}{{u_{z_1}}^2} + \frac{z_2}{{u_{z_2}}^2}}{\frac{1}{{u_{z_1}}^2} + \frac{1}{{u_{z_2}}^2}} \tag{8.3}$$

z_1 and z_2: NIST and CENAM measurements errors in the key comparison (CCM.FF-K6.2011)

$$MVLK(RC) = \frac{\frac{x_1}{{u_{x_1}}^2} + \frac{x_2}{{u_{x_2}}^2}}{\frac{1}{{u_{RCRV}}^2}} \tag{8.4}$$

x_1 and x_2: NIST and CENAM measurements errors in the regional comparison

u_{RCRV}: Weighted value of the standard uncertainty of the RCRV

$$\frac{1}{{u_{RCRV}}^2} = \frac{1}{{u_{x_1}}^2} + \frac{1}{{u_{x_2}}^2} \tag{8.5}$$

Determination of the difference between each laboratory and the RCRV

The difference between each laboratory and the RCRV was calculated using the following formula:

$$d_i = x_i - RCRV \qquad (8.6)$$

The degree of equivalence to the RCRV is defined:

$$E_{n_i} \triangleq \left|\frac{d_i}{U_{E_i}}\right| \qquad (8.7)$$

Since NIST and CENAM values were used to define the RCRV, they have a covariance that results in the variance of the RCRV itself. Therefore

$$u_{E_i} = \sqrt{{u_{d_i}}^2 - {u_{RCRV}}^2} \qquad (8.8)$$

Then, the other participants that did not participate in the calculation of the RCRV have no contribution in the calculation of their uncertainty, since there is no covariance of their results with the RCRV.

$$u_{E_i} = \sqrt{{u_{d_i}}^2 + {u_{RCRV}}^2} \qquad (8.9)$$

$$U_{E_i} = 2.u_{E_i} \qquad (8.10)$$

Uncertainty of measurement

Uncertainties were calculated as presented below.

The uncertainty based on statistical methods of measurement results is calculated using the following equation:

$$u_A = \sqrt{\frac{\sum_{i=1}^{n}(e_i - e_a)^2}{n(n-1)}} \qquad (8.11)$$

Where e_a is the average error at each flow set point reported by the participant.

Other uncertainties were determined by non-statistical methods, with a root-sum-of-squares of the relevant sources of uncertainty from the mathematical model:

$$u_B = \sqrt{\sum_{i=1}^{k} \left(\frac{\partial V_S}{\partial x_i}\right)^2 * u^2(x_i)} \qquad (8.12)$$

The combined uncertainty is calculated as follows:

$$u_C = \sqrt{{u_A}^2 + {u_B}^2} \qquad (8.13)$$

The expanded uncertainty is obtained by multiplying the combined standard uncertainty by coverage factor:

$$U = k\, u_C \qquad (8.14)$$

with the coverage factor k=2, to obtain the approximately 95 % confidence level uncertainty.

9. Results

Error of measurement informed by participants is summarized below.

Flow (m^3/h)	CENAM (%)	INTI (%)	IBMETRO (%)	INACAL (%)	NIST (%)	MC (%)	CDT (%)
2	-0.12	-0.15	-0.44	-0.27	-0.116	-0.02	-0.26
4.5	0.08	-0.12	-0.18	-0.11	0.030	0.15	-0.10
6.6	0.19	0.20	-0.09	-0.06	0.116	0.20	-0.02
9.1	0.20	0.23	0.01	0.10	0.153	0.24	0.03
13.1	0.22	0.22	0.06	0.14	0.170	0.27	0.10
16	0.25	0.25	0.10	0.16	0.196	0.28	0.17
24	0.25	0.32	0.19	0.24	0.219	0.32	0.22
32	0.27	0.34	0.20	0.18	0.240	0.36	0.27
40	0.29	0.34	0.19	0.17	0.263	0.38	0.31
50	0.31	0.31	0.18	0.21	0.315	0.41	0.31
60	0.33	0.41	0.17	0.19	0.358	0.44	0.34
70	0.34	0.39	0.20	0.22	0.404	-	0.38
80	0.36	0.40	0.21	0.18	0.422	-	0.40
90	0.37	0.39	0.21	0.19	0.423	-	0.42
100	0.37	0.48	0.17	0.27	0.421	-	0.42

Table 6. Relative Error of measurement (%), by participant.

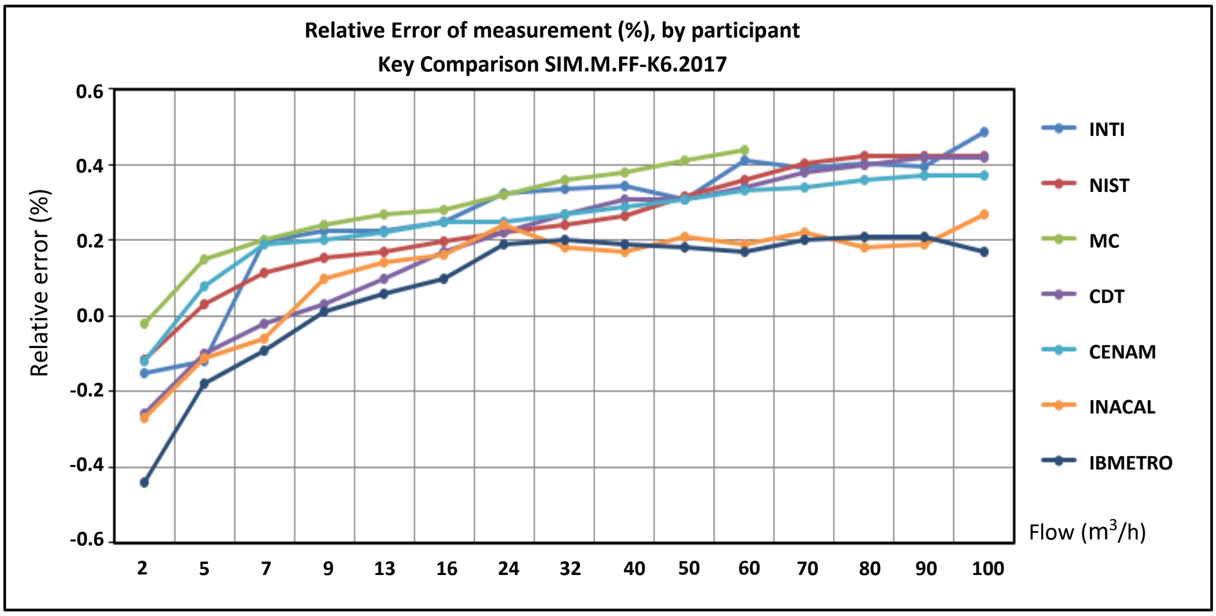


Figure 5. Relative Error of measurement (%), by participant.

Uncertainty of measurement informed by participants is summarized below

Flow (m^3/h)	CENAM (%)	INTI (%)	IBMETRO (%)	INACAL (%)	NIST (%)	MC (%)	CDT (%)
2	0.14	0.18	0.35	0.34	0.104	0.20	0.18
4.5	0.14	0.18	0.35	0.34	0.104	0.20	0.18
6.6	0.14	0.18	0.35	0.34	0.104	0.20	0.21
9.1	0.14	0.18	0.35	0.34	0.104	0.20	0.19
13.1	0.14	0.18	0.35	0.25	0.104	0.20	0.20
16	0.14	0.18	0.35	0.25	0.104	0.20	0.19
24	0.14	0.18	0.35	0.25	0.104	0.20	0.19
32	0.14	0.18	0.35	0.25	0.104	0.20	0.19
40	0.14	0.18	0.35	0.25	0.104	0.20	0.19
50	0.14	0.18	0.35	0.25	0.104	0.20	0.19
60	0.13	0.18	0.35	0.25	0.104	0.20	0.19
70	0.13	0.18	0.35	0.25	0.104	-	0.19
80	0.13	0.18	0.35	0.25	0.104	-	0.19
90	0.13	0.18	0.36	0.25	0.104	-	0.19
100	0.13	0.18	0.36	0.25	0.104	-	0.19

Table 7. Relative expanded uncertainties of measurement (%), informed by participants.

10. The Regional Comparison Reference Value and Its Uncertainty

The values indicated of MVLK(KC) and MVLK(RC) were obtained. Then, the values of RCRV and their uncertainties u_{RCVR} were determined.

Flow	NIST KC		CENAM KC		KCRV		MVLK(KC)	RCC	MVLK(RC)	RCRV	u_{RCRV}
(m^3/h)	e(%)	U(%)	e(%)	U(%)	e(%)	U(%)	(%)	(%)	(%)	(%)	(%)
2	-0.15	0.10	-0.22	0.17	-0.134	0.025	-0.168	0.034	-0.117	**-0.083**	**0.041**
4.5	0.00	0.11	-0.02	0.16	0.017	0.025	-0.006	0.023	0.049	**0.073**	**0.042**
6.6	0.04	0.11	0.02	0.16	0.070	0.024	0.034	0.036	0.144	**0.181**	**0.041**
9.1	0.08	0.10	0.09	0.16	0.107	0.023	0.083	0.024	0.171	**0.196**	**0.041**
13.1	0.10	0.10	0.14	0.15	0.139	0.022	0.112	0.027	0.188	**0.216**	**0.041**
16	0.14	0.10	0.23	0.15	0.165	0.022	0.168	-0.003	0.216	**0.215**	**0.041**
24	0.17	0.10	0.27	0.15	0.189	0.022	0.201	-0.012	0.231	**0.220**	**0.041**
32	0.18	0.10	0.27	0.15	0.214	0.022	0.208	0.006	0.251	**0.258**	**0.041**
40	0.21	0.10	0.30	0.15	0.233	0.022	0.238	-0.005	0.273	**0.269**	**0.041**
50	0.24	0.10	0.31	0.15	0.250	0.022	0.262	-0.012	0.313	**0.301**	**0.042**
60	0.25	0.11	0.30	0.15	0.261	0.022	0.267	-0.006	0.347	**0.340**	**0.041**
70	0.27	0.10	0.31	0.15	0.282	0.023	0.282	0.000	0.379	**0.378**	**0.041**
80	0.29	0.10	0.32	0.15	0.301	0.023	0.299	0.002	0.398	**0.399**	**0.041**
90	0.29	0.10	0.32	0.15	0.314	0.025	0.299	0.015	0.403	**0.416**	**0.041**
100	0.31	0.10	0.33	0.15	0.332	0.025	0.316	0.016	0.401	**0.416**	**0.041**

Table 8. RCRV values and their uncertainties

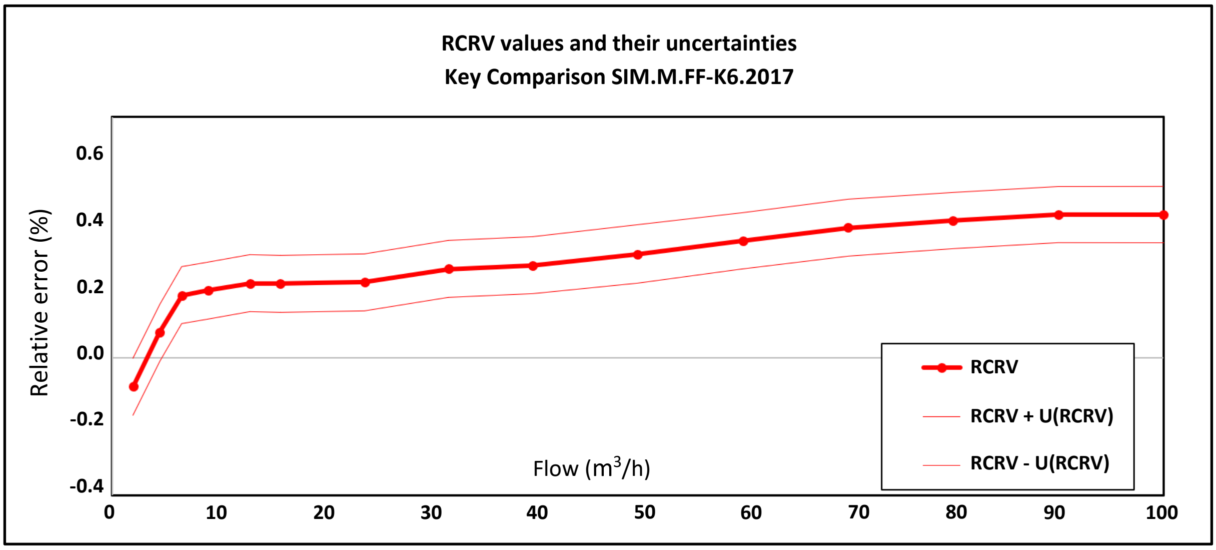


Figure 6. RCRV values and their uncertainties

11. Degrees of Equivalence

The degree of equivalence with the RCRV is a measure of the agreement of the results of each participating laboratory with the RCRV. $E_{n_i} \leq 1$ means that i-th laboratory is in good agreement with RCRV, whereas $E_{n_i} > 1$ means that i-th laboratory is not in a good agreement. The "lab to RCRV" equivalence degrees E_{n_i} are summarized below.

Flow (m^3/h)	CENAM	INTI	IBMETRO	INACAL	NIST	MC	CDT
2	0.29	0.32	0.98	0.53	0.37	0.28	0.85
4.5	0.06	0.94	0.69	0.52	0.49	0.34	0.84
6.6	0.07	0.09	0.74	0.68	0.75	0.08	0.86
9.1	0.04	0.14	0.51	0.27	0.49	0.20	0.77
13.1	0.03	0.04	0.43	0.28	0.53	0.24	0.52
16	0.28	0.16	0.31	0.20	0.21	0.29	0.21
24	0.24	0.50	0.08	0.08	0.00	0.45	0.00
32	0.10	0.38	0.16	0.29	0.21	0.45	0.06
40	0.17	0.36	0.22	0.37	0.07	0.50	0.19
50	0.07	0.03	0.33	0.34	0.15	0.48	0.04
60	0.09	0.33	0.47	0.56	0.20	0.44	0.00
70	0.31	0.06	0.49	0.59	0.30	-	0.01
80	0.32	0.03	0.52	0.81	0.27	-	0.01
90	0.38	0.11	0.55	0.84	0.08	-	0.02
100	0.39	0.33	0.66	0.54	0.06	-	0.02

Table 9. Degree of equivalence to the RCRV

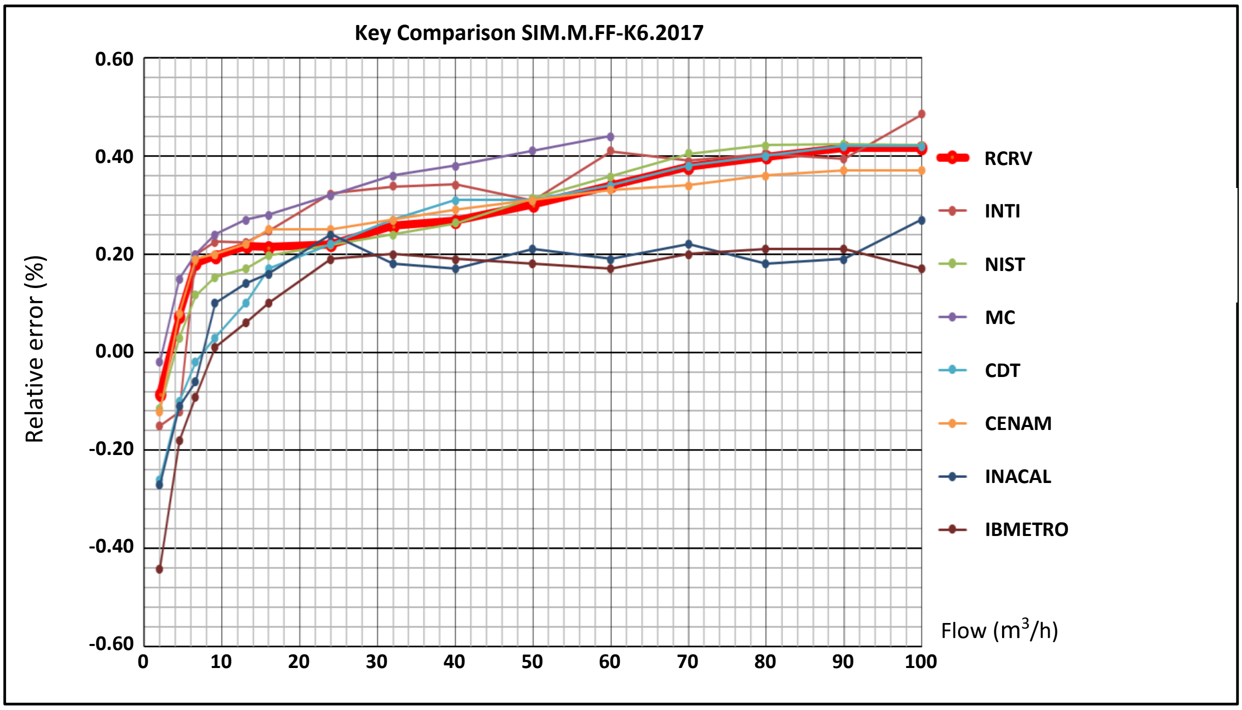


Figure 1: RCRV and each participant error curve

12. Summary and Conclusions

Seven laboratories participated in this regional key comparison: CENAM (Mexico), INTI (Argentina), IBMETRO (Bolivia), INACAL (Perú), NIST (USA), MC (Canada), and CDT (Colombia).

This comparison is linked to CCM.FF-K6.2011. Two participants (CENAM and NIST) provide linkage to the Key Comparison Reference Value (KCRV) of CCM.FF-K6.2011 comparison.

E_{n_i} values were less than 1 for all the flows tested.

All reported results were consistent with the reference value.

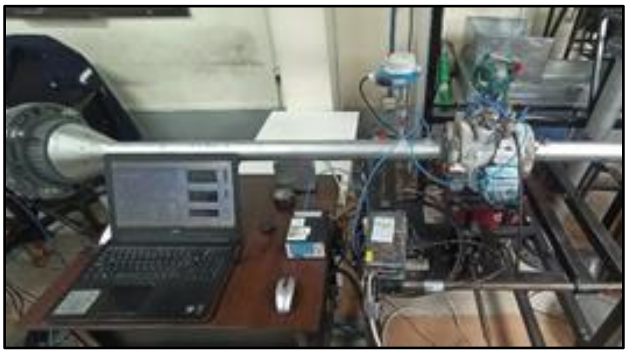
13. Appendices

Appendix A: Facilities used.

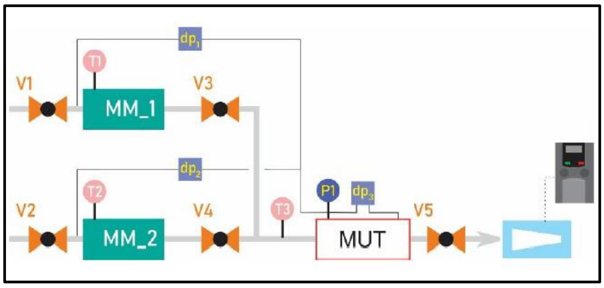
Information	Procedure
CENAM Centro nacional de metrología Mexico Standard: Bell prover Flow: (0.5 to 160) m^3/h Traceability: Traceable to the SI via CENAM Uncertainty: 0.13 % to 0.14 % (*k*=2) Laboratory facilities: 	The bell prover uses a volumetric method to determine gas flow rate. It measures a displaced volume of air by collecting the air at "quasi" constant temperature and pressure conditions. Constant pressure is achieved by using a counter weight and pulley to balance the weight of the bell and by hanging an additional small counter weight from an involute cam to compensate for linear effects as buoyancy. Linear displacement of the bell is measured by means of a linear encoder; which consists of a scale and a scanning head that operates without mechanical contact.

Information	Procedure
INTI Instituto nacional de tecnología industrial Argentina Standard: Bell prover Flow: (0.5 to 100) m^3/h Traceability: Traceable to the SI via INTI Uncertainty: 0.18 % (*k*=2) Laboratory facilities: 	A bell prover with a capacity of 500 liters was used. It consists of a container where a fluid used as a seal rests. The fluid is a light, low-viscosity oil. The measuring bell is submerged in the liquid, floating on the sealing fluid, and is filled with air. As the air is discharged, the bell is submerging into the oil. The depth of immersion is a measure of the volume of air that passed. A proper electronic system is used to measure the volume using an encoder associated with the vertical displacement of the bell.

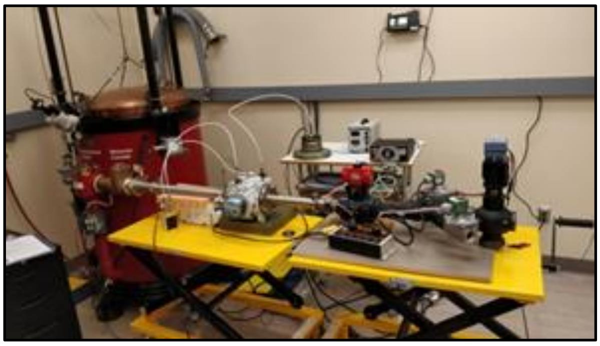
Information	Procedure
IBMETRO	The calibration system installed in the laboratory is composed by two reference standards, G100 and G650, which are switched, according on the gas meter to be calibrated, through a bypass in the pneumatic system. The air flow is produced by an air extractor located at the end of the calibration line. Temperature and pressure are monitored as on the standard meters as on the instrument under calibration. All of these sensor parameters, including the pulse counters are acquired by a data logger and collected and processed by a routine developed in LabVIEW system.
Instituto boliviano de metrología	
Bolivia	
Standard: Rotary piston meters	
Flow: (1 to 160) m^3/h	
Traceability: Traceable to the SI via external laboratory	
Uncertainty: 0.35 % to 0.36 % (k=2)	
Laboratory facilities:	



Information	Procedure
INACAL	The method used is that of direct comparison against rotary-type standard meters, using atmospheric air as the test fluid.
Instituto nacional de calidad	
Perú	
Standard: Rotary piston meters	
Flow: (2 to 1 000) m^3/h	
Traceability: Traceable to the SI via external laboratory	
Uncertainty: 0.25 % to 0.34 % (k=2)	
Laboratory facilities:	



Information	Procedure
NIST	The WGFS uses a set of eight CFVs with throat diameters between 0.29 mm and 6.35 mm or a set of nine critical nozzles (i.e. no diverging section downstream from the throat) available with throat diameters between 3.5 mm and 33 mm. These two sets of working standards (generically both referred to as nozzles herein) cover flows over the range of 1 L/min to 70 000 L/min. The CFVs have 25 mm fittings with o-ring seals.
National institute of standards and technology	
USA	
Standard: Critical flow venturis	
Flow: (0.06 to 4 200) m^3/h	
Traceability: Traceable to the SI via NIST	
Uncertainty: 0.104 % (k=2)	
Laboratory facilities: 	

Information	Procedure
MC	Measurement Canada's 10ft³ master bell prover is the reference standard used for the comparison. The bell prover is calibrated by strapping of the bell diameter at various scale plate markings across the 10 ft³ volume. The net displaced volume is determined from the bell's cross-sectional area, the travel distance relative to the scale plate reading, and the oil rise. Measurement Canada's Master Bell Prover is an automated proving system with integrated pressure and temperature measurement.
Innovation, science, and economic development Government of Canada	
Canada	
Standard: Bell prover	
Flow: (1.4 to 65) m^3/h	
Traceability: Traceable to the SI via external laboratory	
Uncertainty: 0.20 % (k=2)	
Laboratory facilities: 	

Information	Procedure
CDT	The bell prover and set of rotary piston meters of the CDT de GAS calibration laboratory, allows the calibration of gas volume meters in the measurement range between 0.016 to 4 800 m^3/h. The calibration method consists of the direct comparison between the volume of the meter under test and the volume displaced in the standard, corrected to the thermodynamic conditions of the meter under test.
Corporación centro de desarrollo tecnológico del gas	
Colombia	
Standard: Bell prover and rotary piston meters	
Flow: (0.016 to 4 800) m^3/h	
Traceability: Traceable to the SI via internal and external laboratories	
Uncertainty: 0.18 to 0.21 % (*k*=2)	
Laboratory facilities:	

Appendix B: Results by participant

CENAM, Centro Nacional de Metrología. MEXICO

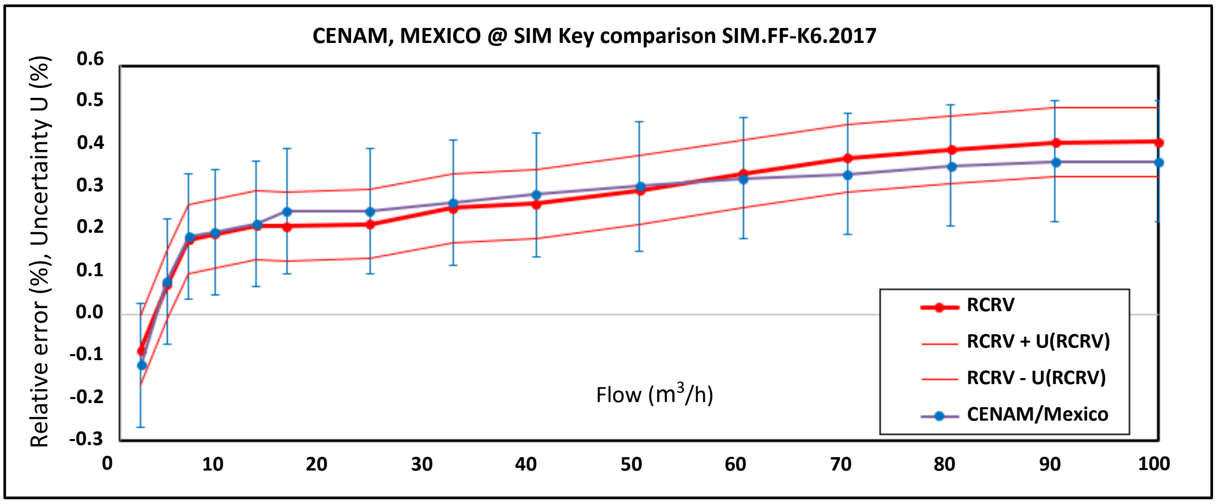


Figure B.1. RCRV vs error and uncertainty of measurement, CENAM, Mexico.

Q (m^3/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.12	0.14	-0.04	0.29
4.5	0.08	0.14	0.01	0.06
6.6	0.19	0.14	0.01	0.07
9.1	0.20	0.14	0.01	0.04
13.1	0.22	0.14	0.00	0.03
16	0.25	0.14	0.04	0.28
24	0.25	0.14	0.03	0.24
32	0.27	0.14	0.01	0.10
40	0.29	0.14	0.02	0.17
50	0.31	0.14	0.01	0.07
60	0.33	0.13	-0.01	0.09
70	0.34	0.13	-0.04	0.31
80	0.36	0.13	-0.04	0.32
90	0.37	0.13	-0.05	0.38
100	0.37	0.13	-0.05	0.39

Table B.1. Results details, CENAM, Mexico

Q Nominal Flow of the transfer standard.

e_{x_i} Relative error of the transfer standard.

U_{x_i} Expanded uncertainty of measurement declared by laboratory.

d_{x_i} Difference between laboratory value and the RCVR.

E_{n_i} Degree of equivalence to the RCRV.

INTI, Instituto Nacional de Tecnología Industrial. ARGENTINA

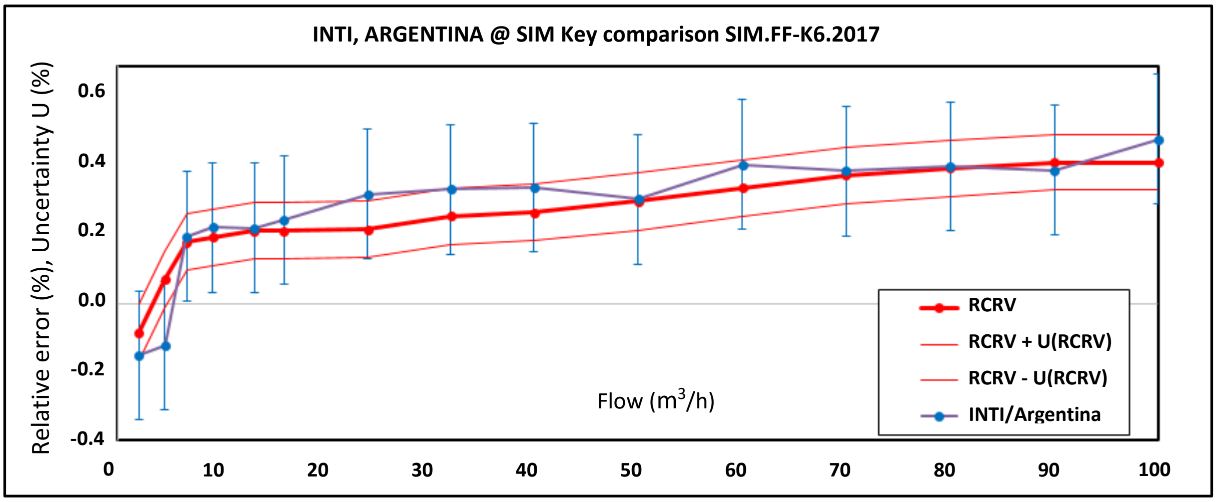


Figure B.2. RCRV vs error and uncertainty of measurement, INTI, Argentina.

Q (m^3/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.15	0.18	-0.07	0.32
4.5	-0.12	0.18	-0.19	0.94
6.6	0.20	0.18	0.02	0.09
9.1	0.23	0.18	0.03	0.14
13.1	0.22	0.18	0.01	0.04
16	0.25	0.18	0.03	0.16
24	0.32	0.18	0.10	0.50
32	0.34	0.18	0.08	0.38
40	0.34	0.18	0.07	0.36
50	0.31	0.18	0.01	0.03
60	0.41	0.18	0.07	0.33
70	0.39	0.18	0.01	0.06
80	0.40	0.18	0.01	0.03
90	0.39	0.18	-0.02	0.11
100	0.48	0.18	0.07	0.33

Table B.2. Results details, INTI, Argentina

IBMETRO, Instituto Boliviano de Metrología. BOLIVIA

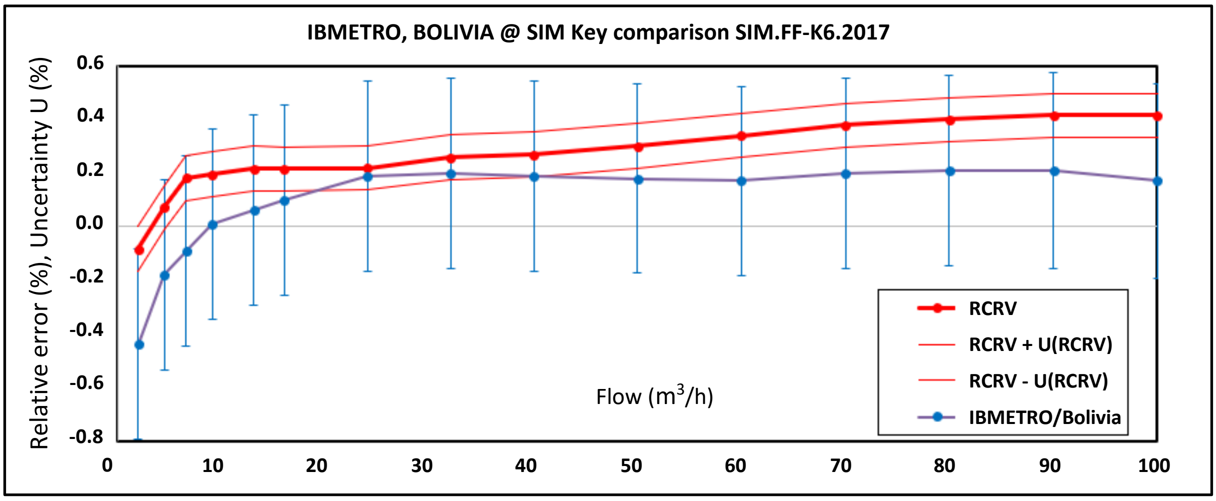


Figure B.3. RCRV vs error and uncertainty of measurement, IBMETRO, Bolivia.

Q (m³/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.44	0.35	-0.36	0.98
4.5	-0.18	0.35	-0.25	0.69
6.6	-0.09	0.35	-0.27	0.74
9.1	0.01	0.35	-0.19	0.51
13.1	0.06	0.35	-0.16	0.43
16	0.10	0.35	-0.11	0.31
24	0.19	0.35	-0.03	0.08
32	0.20	0.35	-0.06	0.16
40	0.19	0.35	-0.08	0.22
50	0.18	0.35	-0.12	0.33
60	0.17	0.35	-0.17	0.47
70	0.20	0.35	-0.18	0.49
80	0.21	0.35	-0.19	0.52
90	0.21	0.36	-0.21	0.55
100	0.17	0.36	-0.25	0.66

Table B.3. Results details, IBMETRO, Bolivia

INACAL, Instituto Nacional de Calidad. PERU

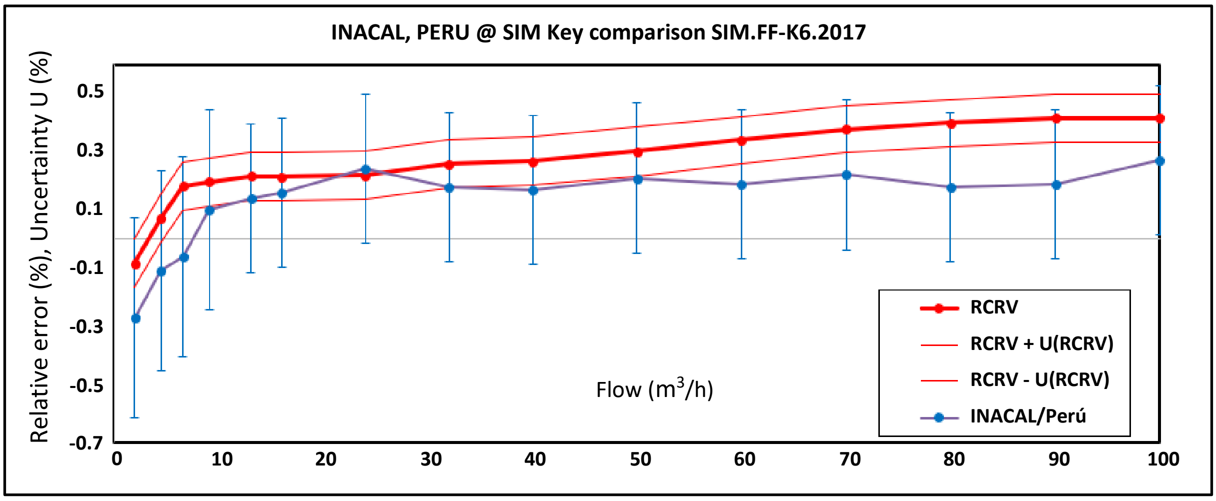


Figure B.4. RCRV vs error and uncertainty of measurement, INACAL, Perú.

Q (m^3/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.27	0.34	-0.19	0.53
4.5	-0.11	0.34	-0.18	0.52
6.6	-0.06	0.34	-0.24	0.68
9.1	0.10	0.34	-0.10	0.27
13.1	0.14	0.25	-0.08	0.28
16	0.16	0.25	-0.05	0.20
24	0.24	0.25	0.02	0.08
32	0.18	0.25	-0.08	0.29
40	0.17	0.25	-0.10	0.37
50	0.21	0.25	-0.09	0.34
60	0.19	0.25	-0.15	0.56
70	0.22	0.25	-0.16	0.59
80	0.18	0.25	-0.22	0.81
90	0.19	0.25	-0.23	0.84
100	0.27	0.25	-0.15	0.54

Table B.4. Results details, INACAL, Perú

NIST, National Institute of Standards and Technology. USA

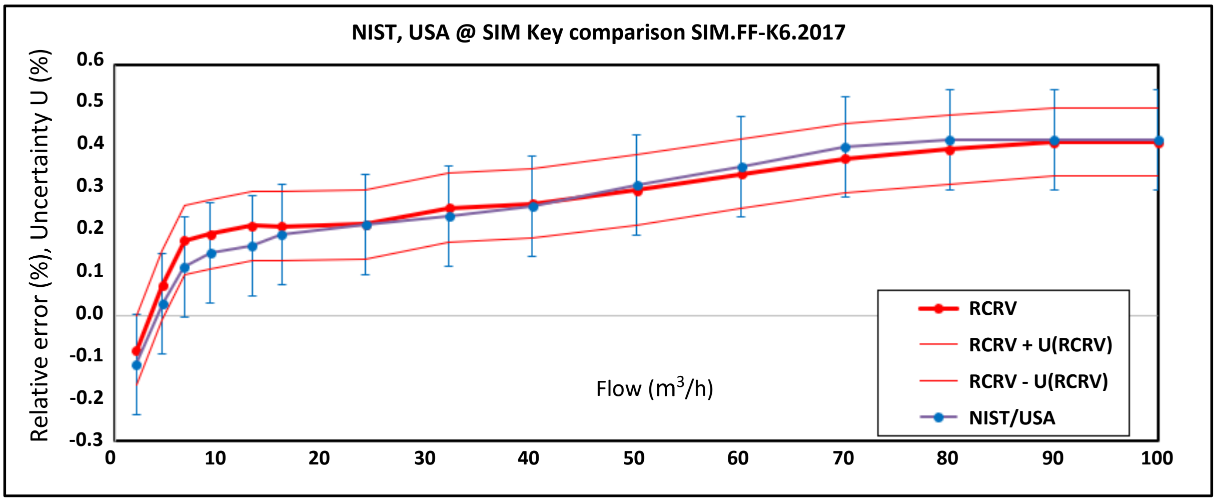


Figure B.5. RCRV vs error and uncertainty of measurement, NIST, USA.

Q (m³/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.116	0.104	-0.032	0.37
4.5	0.030	0.104	-0.043	0.49
6.6	0.116	0.104	-0.065	0.75
9.1	0.153	0.104	-0.043	0.49
13.1	0.170	0.104	-0.046	0.53
16	0.196	0.104	-0.018	0.21
24	0.219	0.104	0.000	0.00
32	0.240	0.104	-0.018	0.21
40	0.263	0.104	-0.006	0.07
50	0.315	0.104	0.013	0.15
60	0.358	0.104	0.018	0.20
70	0.404	0.104	0.026	0.30
80	0.422	0.104	0.023	0.27
90	0.423	0.104	0.007	0.08
100	0.421	0.104	0.005	0.06

Table B.5. Results details, NIST, USA

MC, Innovation, Science and Economic Development Canada / Government of Canada. CANADA

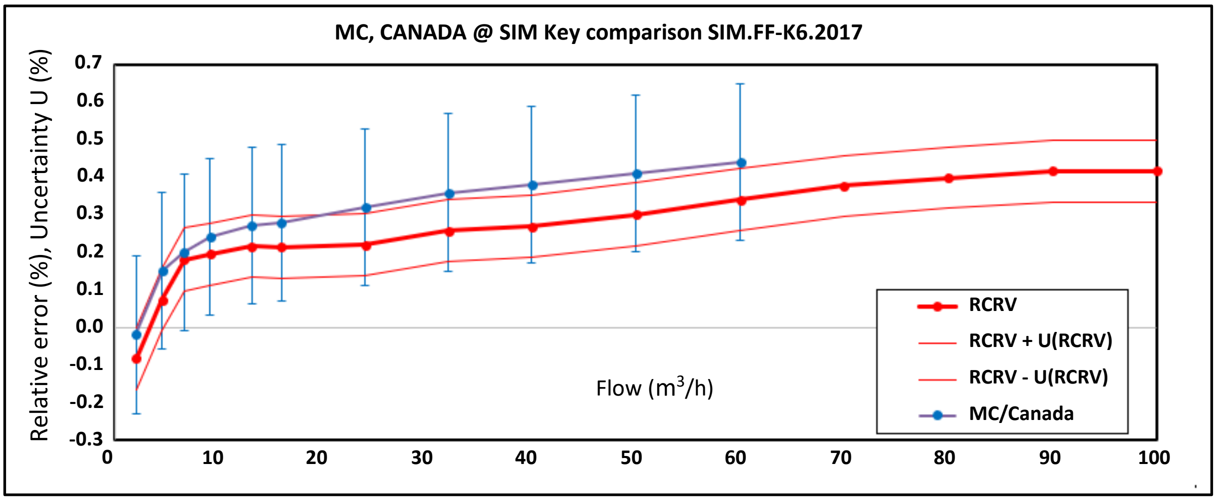


Figure B.6. RCRV vs error and uncertainty of measurement, MC, Canada.

Q (m³/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.02	0.20	0.06	0.28
4.5	0.15	0.20	0.08	0.34
6.6	0.20	0.20	0.02	0.08
9.1	0.24	0.20	0.04	0.20
13.1	0.27	0.20	0.05	0.24
16	0.28	0.20	0.07	0.29
24	0.32	0.20	0.10	0.45
32	0.36	0.20	0.10	0.45
40	0.38	0.20	0.11	0.50
50	0.41	0.20	0.11	0.48
60	0.44	0.20	0.10	0.44
70	-	-	-	-
80	-	-	-	-
90	-	-	-	-
100	-	-	-	-

Table B.6. Results details, MC, Canada

CDT, Corporación Centro de Desarrollo Tecnológico del Gas. COLOMBIA

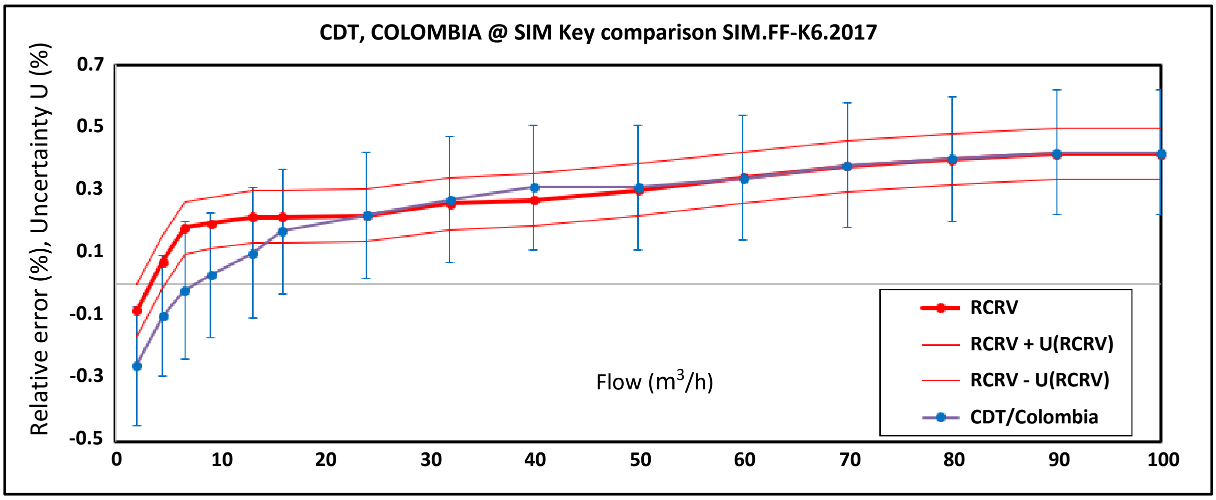


Figure B.7. RCRV vs error and uncertainty of measurement, CDT, Colombia.

Q (m^3/h)	e_{x_i} (%)	U_{x_i} (%)	d_{x_i} (%)	E_{n_i}
2	-0.26	0.18	-0.18	0.85
4.5	-0.10	0.18	-0.17	0.84
6.6	-0.02	0.21	-0.20	0.86
9.1	0.03	0.19	-0.17	0.77
13.1	0.10	0.20	-0.12	0.52
16	0.17	0.19	-0.04	0.21
24	0.22	0.19	0.00	0.00
32	0.27	0.19	0.01	0.06
40	0.31	0.19	0.04	0.19
50	0.31	0.19	0.01	0.04
60	0.34	0.19	0.00	0.00
70	0.38	0.19	0.00	0.01
80	0.40	0.19	0.00	0.01
90	0.42	0.19	0.00	0.02
100	0.42	0.19	0.00	0.02

Table B.7. Results details, CDT, Colombia

14. References

1 - Final report Comparison of the Primary (National) Standards of Low-Pressure Gas Flow - CIPM key comparison CCM.FF-K6.2011.

2 - JCGM 100:2008 (GUM 1995 with minor corrections) Evaluation of measurement data — Guide to the expression of uncertainty in measurement.