FINAL REPORT

Supplementary Comparison SIM.M.P-S10
Pneumatic Gauge Pressure Comparison from 700 kPa to 7 000 kPa

Leonardo De la Cruz[1], Jorge Torres[2], Adrián Solano[3], Marcial Espinoza[4], Maria Neyra[5], Pablo Constantino[6], Jesús Aranzolo[2], Ricardo Sánchez[1]

1 Instituto Nacional de Calidad, INACAL
2 Centro Nacional de Metrología de México, CENAM
3 Laboratorio Costarricense de Metrología, LACOMET
4 Empresa Nacional de Aeronáutica, ENAER
5 Instituto Nacional de Metrología, INM
6 Laboratorio Tecnológico del Uruguay, LATU

ABSTRACT

This report presents the final results of the supplementary comparison SIM.M.P-S10 for pneumatic gauge pressure from 700 kPa to 7 000 kPa. This comparison was carried out in the period from November 2014 to January 2015, by using a digital pressure manometer with uncertainty* 0.010 % of the reading as the transfer standard for the comparison. The reference value for this comparison was given by the Centro Nacional de Metrologia de Mexico (CENAM, Mexico).

CONTENT

* Manufacturer's specification sheet

1. INTRODUCTION

This supplementary comparison is aimed to confirm and strengthen the calibration and measurement capabilities (CMCs) in the range from 700 kPa to 7 000 kPa pneumatic gauge pressure. Also, it allows stating the level of agreement among the participating National Metrology Institutes (NMIs) with respect to the reference value provided by the Centro Nacional de Metrología de México (CENAM). The comparison was carried out within the Inter-American Metrology System and identified as SIM.M.P-S10. It was funded by the Perez-Guerrero Trust Fund for Economic and Technical Cooperation among Developing Countries.

2. OBJECTIVES

The objectives were to determine the differences between errors, with their associated uncertainties, of the participant NMIs with the reference values provided by CENAM for the calibration of pneumatic gauge pressure in the range from 700 kPa to 7 000 kPa with uncertainty 0.010 % of the reading.

3. TRANSFER STANDARD (TS) CHARACTERISTICS

The instrument used as transfer standard is a digital pressure manometer with the following characteristics:

Indication interval	: 0 kPa to 7 000 kPa
Resolution	: 0,001 kPa
Brand	: FLUKE
Model	: RPM4 A7Ms
Serial number	: 2261
Uncertainty	: 0.010 % of the reading

4. PARTICIPANTS, MEASUREMENT PROGRAM AND STANDARDS USED

Table 1 shows the NMIs that participated in this comparison. The measurement round started and finished at the Centro Nacional de Metrologia de Mexico (CENAM) as shown in Figure 1. Nominal pressure values compared were: 700 kPa, 1 400 kPa, 2 100 kPa, 2 800 kPa, 3 500 kPa, 4 200 kPa, 4 900 kPa, 5 600 kPa, 6 300 kPa and 7 000 kPa.

Table 1. Participants, schedule and technical specifications of standards used.

Country	COLOMBIA	PERU	CHILE	COSTA RICA	URUGUAY	MEXICO
NMI	INM	INACAL	ENAER	LACOMET	LATU	CENAM
Measurement Date	2014-11-11 to 2014-11-14	2014-11-18 to 2014-11-21	2014-11-25 to 2014-11-28	2014-12-03 to 2014-12-05	2014-12-10 to 2014-12-12	2014-11-04 to 2014-11-06 and 2015-01-28 to 2015-01-30
Contact	Maria Catalina Neyra mneira@inm.gov.co	Leonardo De la cruz ldelacruz@inacal.gob.pe	Marcial Espinoza mespinoza@enaer.cl	Fernando Andrés Adrian Solano asolano@lacomet.go.cr	Pablo Constantino pconstan@latu.org.uy	Jorge Torres Guzmán jtorres@cenam.mx
Fluid	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Standard Used	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance	Pressure Balance
Brand	DH Instruments	DH Instruments	RUSKA	DH Instruments	DH Instruments	DH Instruments
Model	PG-7601	PG-7601	2465-A	PG-7601	PG - 7102	PG-7601
Serial Number	Base: 584 Pistón: 1143	Base: 716; Pistón: 1390	Base: 53860; Pistón: V-1518	Base: 583; Pistón: 1152	Base: 729; Pistón: 1426	Base: 107; Pistón: 228
Indication Interval	40 kPa to 7 000 kPa	40 kPa to 7 000 kPa	14 kPa to 7000 kPa	700 kPa to 7000 kPa	7 000 kPa	40 kPa to 7 000 kPa
accuracy class	0,002%R	0,003%R	0,005%R	0.0025 %R	0,003%R	10 Pa or 0,005%R or greater
Cylinder Material	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide
Piston Material	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide	Tungsten Carbide
Effective Area - Zero Pressure (A_0) in m^2	4,901899E-05	4,9019147E-05	8,38702E-06	4,90233E-05	4,90280E-05	4,90267E-05
Relative Uncertainty of A_0 in 10^{-6}	18	21	18	13,5	20	19
Elastic Deformation Coefficient b in Pa^{-1}	-2,35E-12	-2,30E-13	1,20E-12	-2,35E-12	1,73E-12	2,10E-14
Uncertainty of b in Pa^{-1}	6E-13	5,4E-13	1,00E-12	5,4E-13	1,50E-12	4,90E-13
Metrological Traceability	PTB - Alemania	CENAM - México	PTB - Alemania	CEM - España	CENAM - México	CENAM

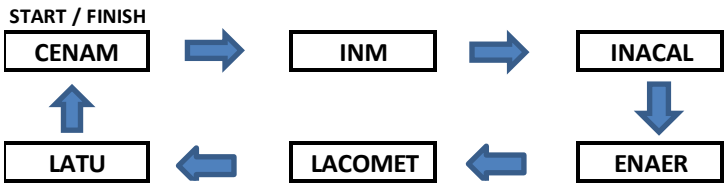

Figure 1. Measurements comparison round.

5. MEASUREMENT PROCEDURE

International comparisons performed by both CIPM and SIM [1, 2] were used only as bibliographic references for this comparison. The measurement method used in this comparison was the direct comparison method, according to the comparison protocol [3]. All participant NMIs used a pressure balance as reference standard, as well as their own procedures and calculations in order to achieve the nominal pressure values.

5.1 Error

The indication error was determined by the following equation:

$$E_{lab} = P_{TS} - P_{LAB} \quad (1)$$

where:

E_{lab} = error obtained by the laboratory;

P_{TS} = corrected pressure, generated by the transfer standard;

P_{LAB} = corrected pressure, generated by the laboratory standard.

Note: In the corrected pressures (P_{TS} and P_{LAB}) the zero indications have been considered.

5.2 Uncertainty

To assess the uncertainty, the participating NMIs considered the following uncertainty sources:

- Uncertainty due to the laboratory standard used;
- Uncertainty due to repeatability;
- Uncertainty due to resolution;
- Uncertainty due to hysteresis;
- Uncertainty due to zero drift;
- Uncertainty due to column pressure.

Measurement uncertainties were reported to two significant digits, with a confidence level of at least 95 % and the corresponding coverage factor.

6. RESULTS

Based on calibrations performed by CENAM (at the beginning and at the end of the comparison measurements round), the drift of the transfer standard was determined. The drift of the transfer standard used for the comparison was constant for the whole measuring range. The two calibrations carried out by CENAM, CENAM 1 and CENAM 2, and the constant drift (difference between the two calibrations) are shown in Figure 2. The drift of the transfer standard was less than 210 Pa for the whole measuring range.

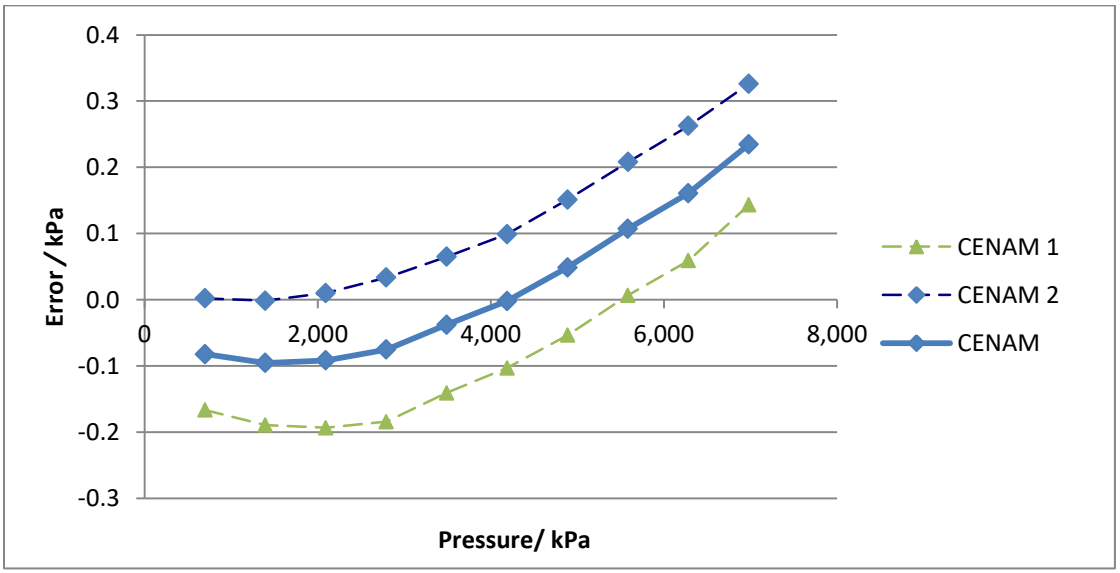

Figure 2. Calibrations performed by CENAM in the range from 700 kPa to 7 000 kPa, showing the drift of the transfer standard.

The uncertainties of the two CENAM's calibrations are similar. For the comparison the values presented for CENAM are: a) for the error, the average between the first and second calibration; b) for the uncertainty, the uncertainty of the first calibration.

Table 2 presents the results of the participating laboratories. Figure 3 shows the error curves of the TS found by the laboratories. In Figure 4 the errors and its corresponding uncertainties are graphed.

Table 2. Results reported by NMIs (error and expanded uncertainty).

	CHILE		COSTA RICA		COLOMBIA		URUGUAY		PERU		MEXICO	
Nominal Pressure	Error	*U*	Error	*U*	Error	*U*	Error	*U*	Error	*U*	Error	*U*
kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa	kPa
700.00	-0.17	0.08	-0.04	0.10	-0.11	0.08	-0.07	0.10	-0.10	0.12	-0.08	0.07
1 400.00	-0.18	0.11	-0.04	0.13	-0.10	0.12	-0.10	0.13	-0.09	0.15	-0.10	0.11
2 100.00	-0.17	0.14	-0.04	0.16	-0.10	0.14	-0.09	0.14	-0.09	0.16	-0.09	0.12
2 800.00	-0.16	0.16	-0.04	0.18	-0.10	0.15	-0.07	0.15	-0.07	0.18	-0.08	0.14
3 500.00	-0.15	0.17	-0.03	0.19	-0.08	0.16	-0.05	0.16	-0.04	0.20	-0.04	0.15
4 200.00	-0.13	0.18	-0.01	0.20	-0.07	0.16	-0.01	0.17	0.00	0.18	0.00	0.15
4 900.00	-0.09	0.18	0.02	0.21	-0.03	0.16	0.05	0.17	0.05	0.18	0.05	0.15
5 600.00	-0.08	0.17	0.05	0.19	-0.01	0.15	0.11	0.17	0.10	0.16	0.11	0.14
6 300.00	-0.04	0.18	0.08	0.19	0.02	0.15	0.17	0.17	0.14	0.15	0.16	0.14
7 000.00	-0.01	0.19	0.12	0.19	0.07	0.15	0.25	0.18	0.23	0.15	0.23	0.14

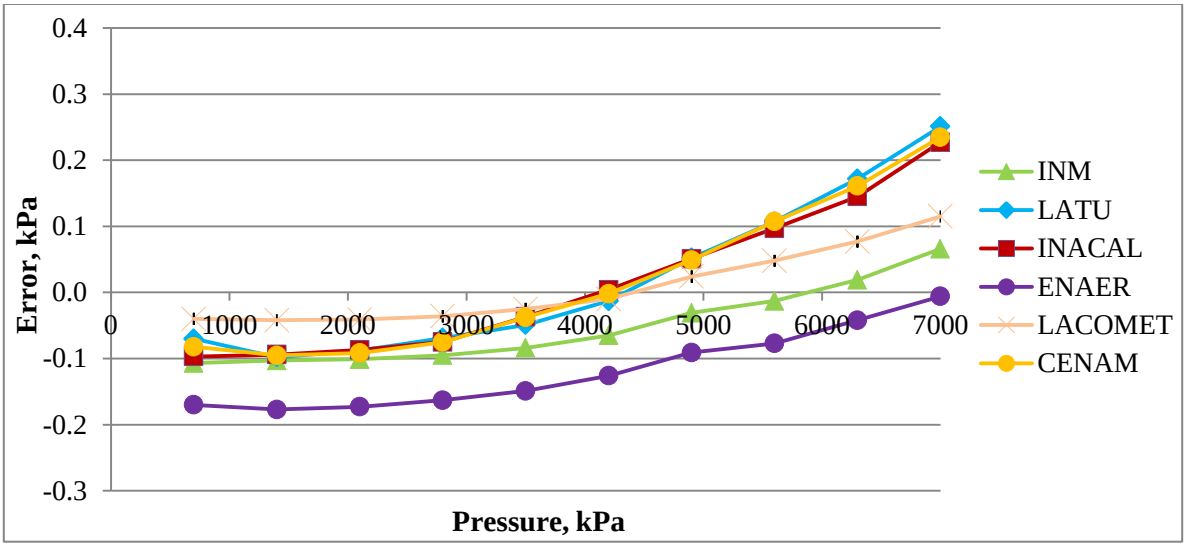

Figure 3. Transfer standard error curves obtained by participant laboratories in the range from 700 kPa to 7 000 kPa.

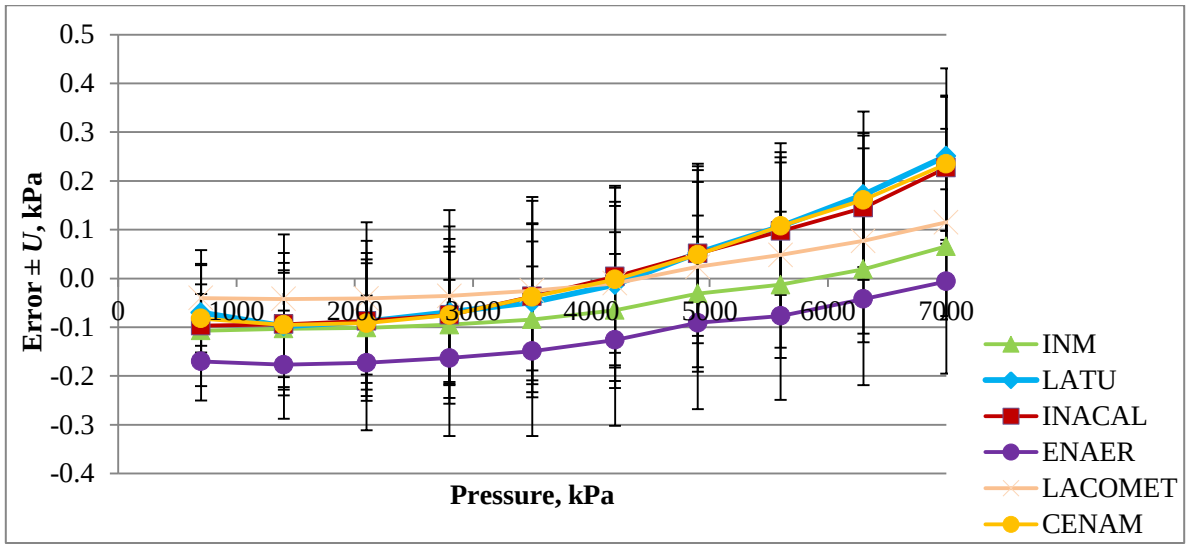

Figure 4. Transfer standard error curves and expanded uncertainty obtained by participant laboratories in the range from 700 kPa to 7 000 kPa.

Figures from 5 to 14 show errors and expanded uncertainties found by each participant NMI for each pressure target point.

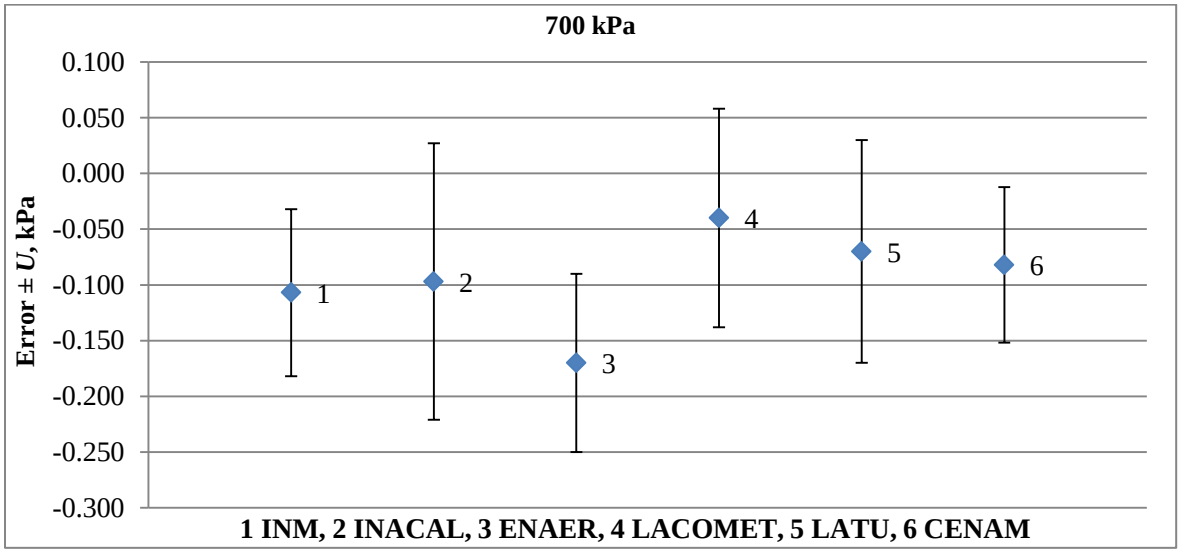

Figure 5. Transfer standard error and uncertainty reported by participant laboratories at 700 kPa.

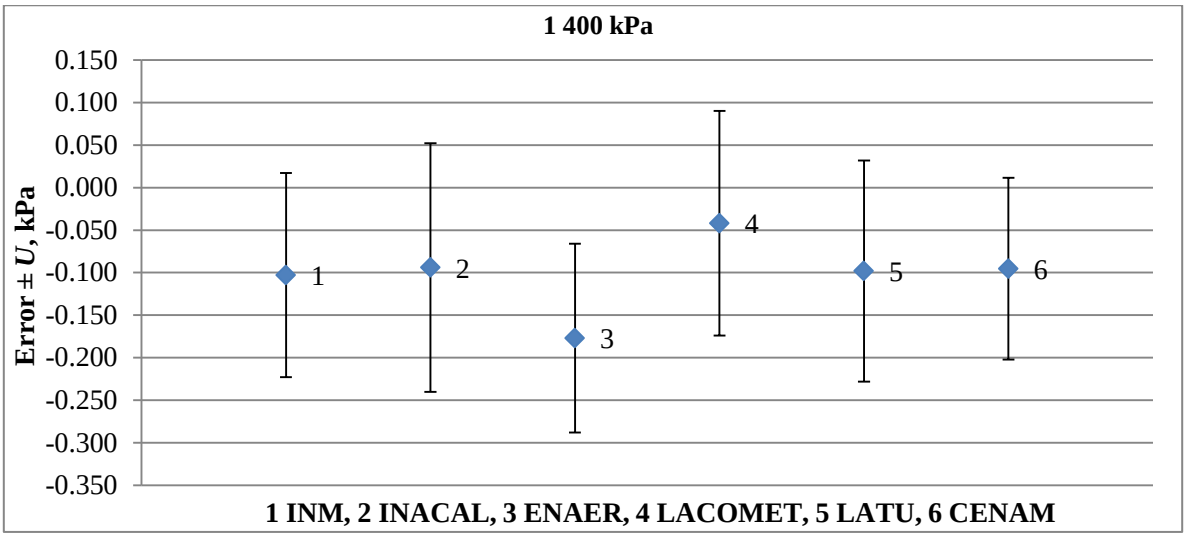

Figure 6. Transfer standard error and uncertainty reported by participant laboratories at 1 400 kPa.

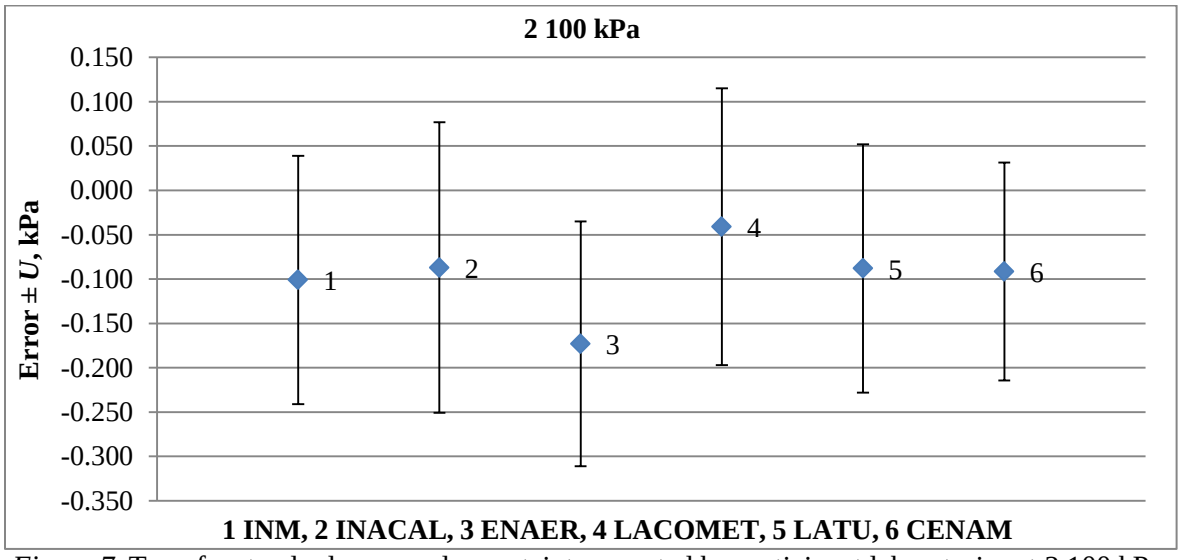

Figure 7. Transfer standard error and uncertainty reported by participant laboratories at 2 100 kPa.

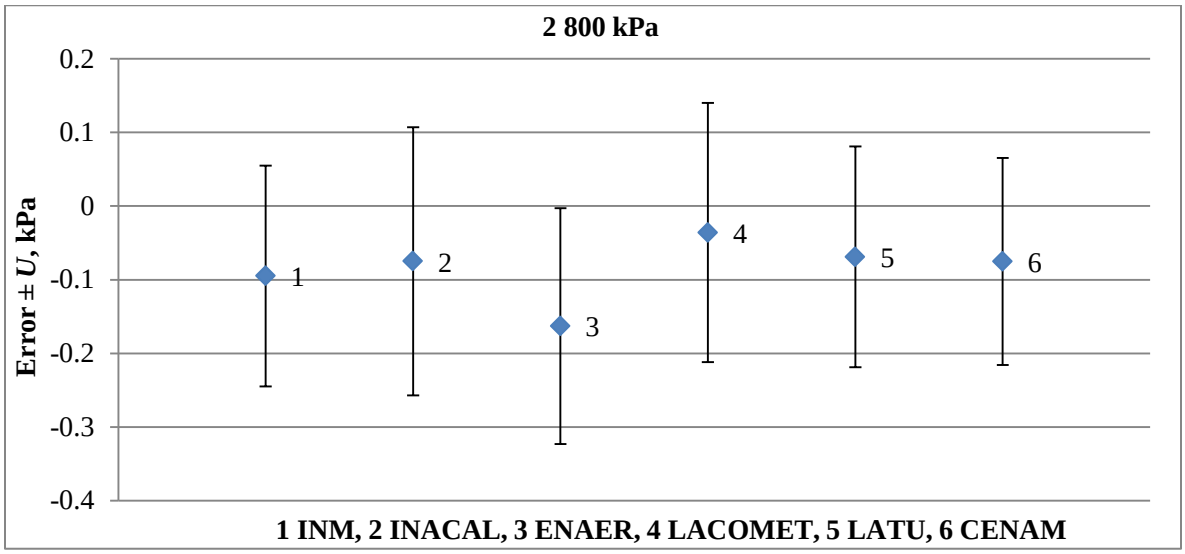

Figure 8. Transfer standard error and uncertainty reported by participant laboratories at 2 800 kPa.

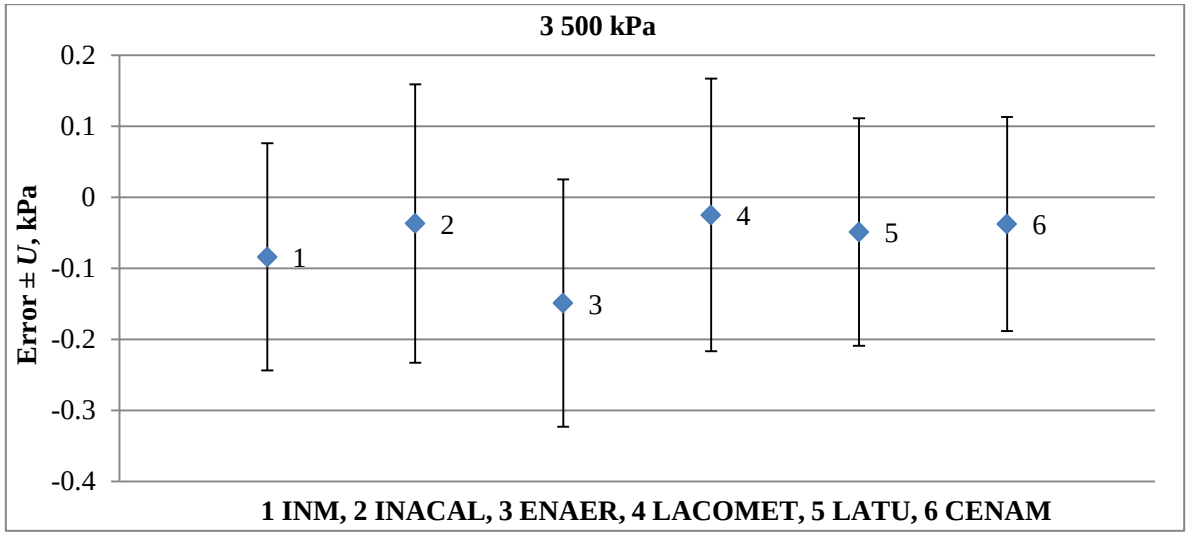

Figure 9. Transfer standard error and uncertainty reported by participant laboratories at 3 500 kPa.

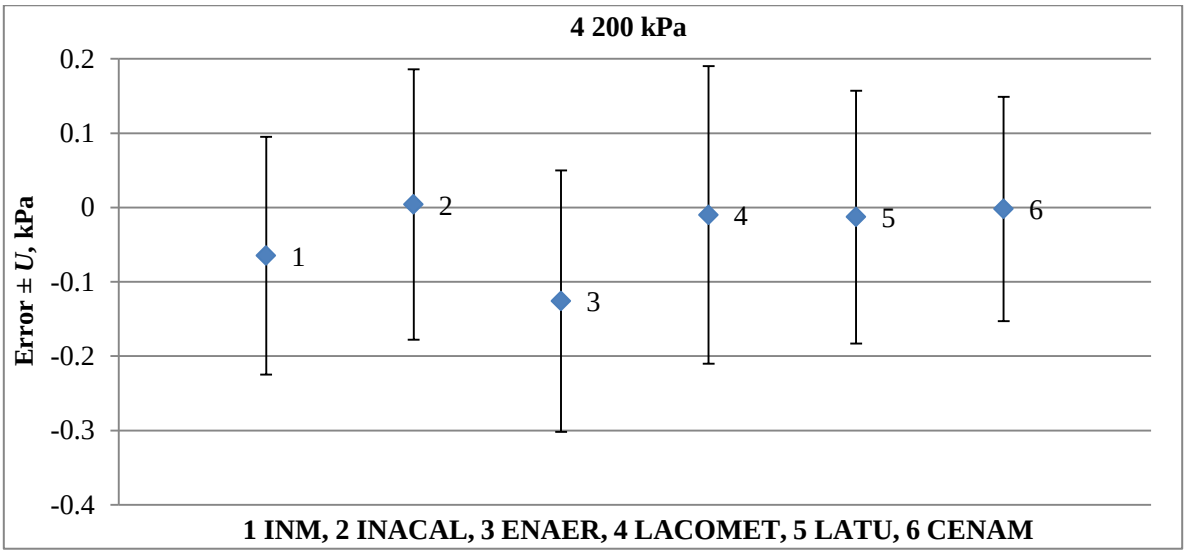

Figure 10. Transfer standard error and uncertainty reported by participant laboratories at 4 200 kPa.

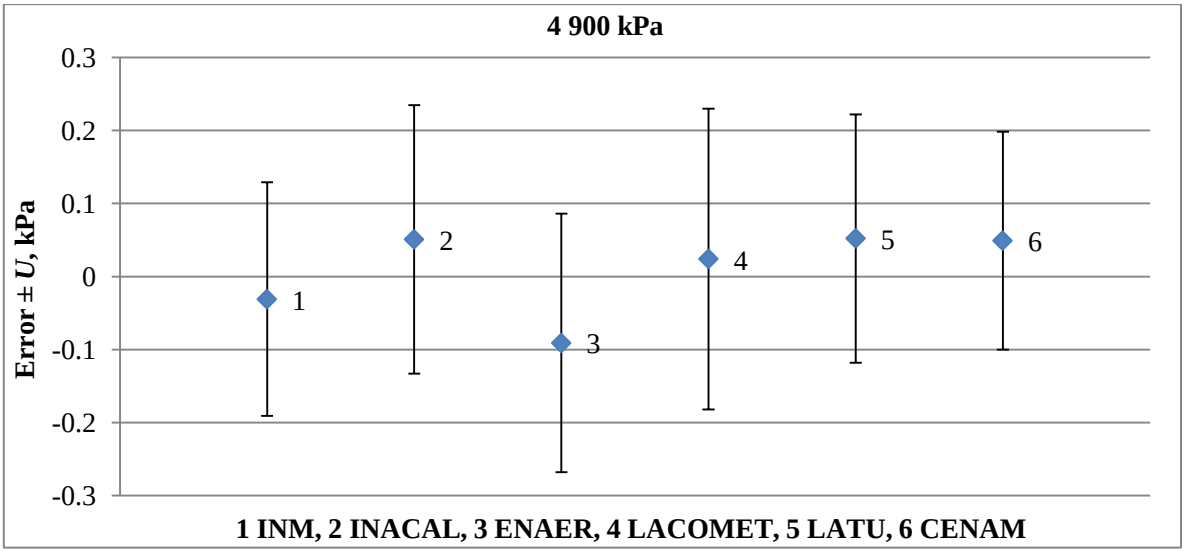

Figure 11. Transfer standard error and uncertainty reported by participant laboratories at 4 900 kPa.

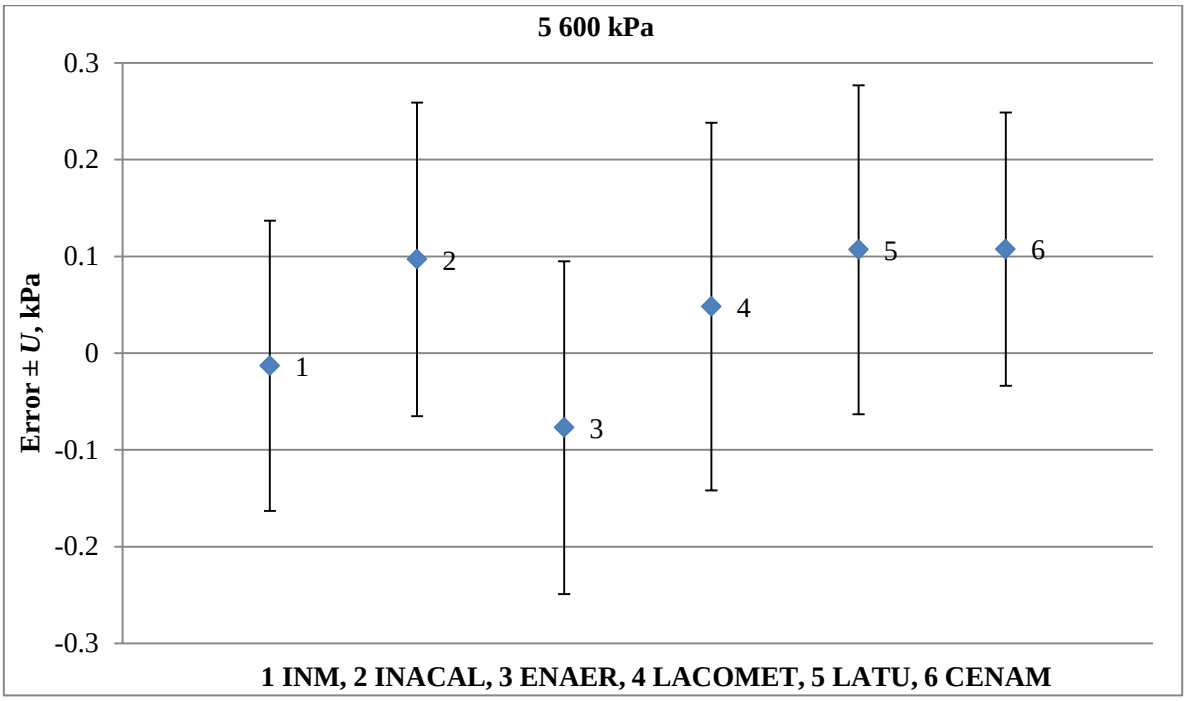

Figure 12. Transfer standard error and uncertainty reported by participant laboratories at 5 600 kPa.

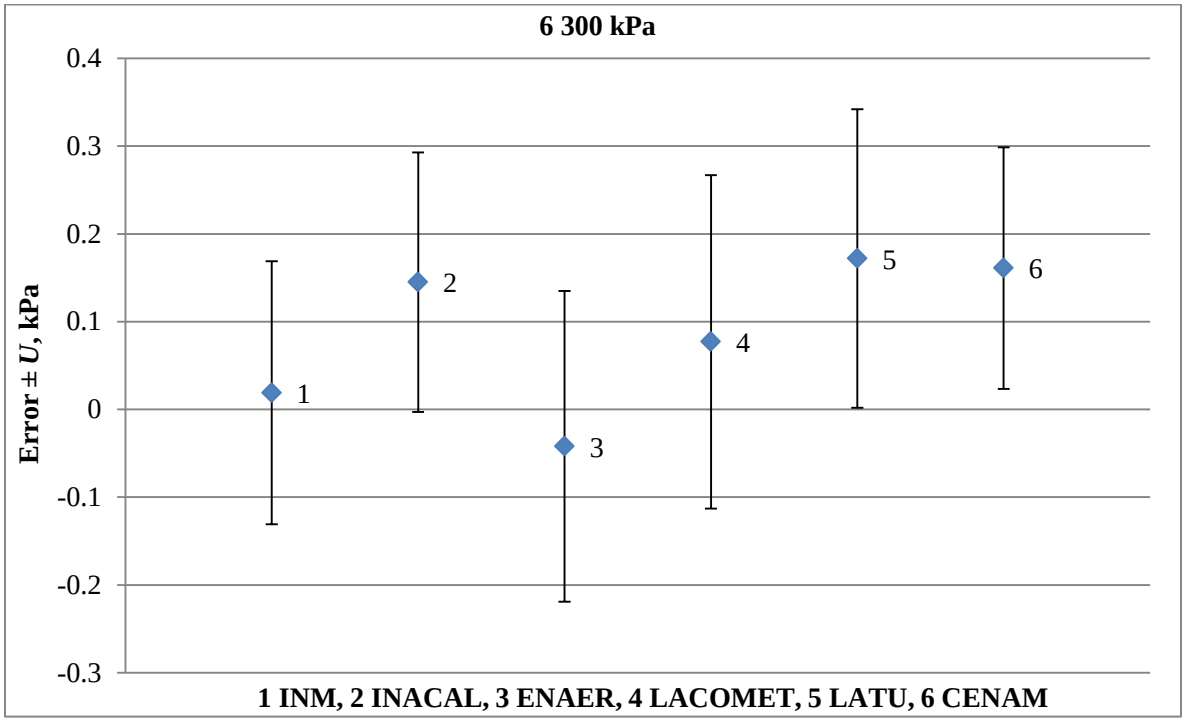

Figure 13. Transfer standard error and uncertainty reported by participant laboratories at 6 300 kPa.

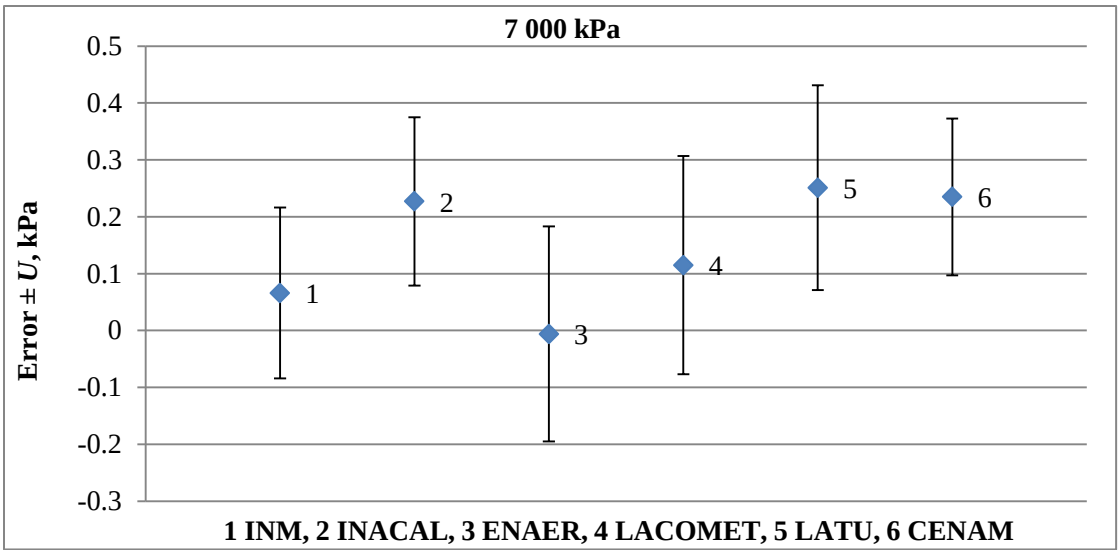

Figure 14. Transfer standard error and uncertainty reported by participant laboratories at 7 000 kPa.

7. RESULTS EVALUATION

7.1 Reference values

The reference values were set based on CENAM´s error and uncertainty.

The comparison reference error was set as the average from the first and last calibrations made by CENAM, as:

$$E_{ref} = \frac{(E_{CENAM-initial} + E_{CENAM-final})}{2} \quad (2)$$

Table 3. The calibrations carried out by CENAM

Nominal Pressure (kPa)	$E_{CENAM\text{-}initial}$ (kPa)	$E_{CENAM\text{-}final}$ (kPa)	E_{ref} (kPa)
700.00	-0.17	0.00	-0.08
1 400.00	-0.19	0.00	-0.10
2 100.00	-0.19	0.01	-0.09
2 800.00	-0.18	0.03	-0.08
3 500.00	-0.14	0.07	-0.04
4 200.00	-0.10	0.10	0.00
4 900.00	-0.05	0.15	0.05
5 600.00	0.01	0.21	0.11
6 300.00	0.06	0.26	0.16
7 000.00	0.14	0.33	0.23

The comparison reference uncertainty was set as the combined uncertainty of the uncertainty of the initial calibration made by CENAM with that due to the drift of the TS (drift obtained by the difference from the first and last calibrations made by CENAM), as:

$$u(E_{ref}) = \sqrt{u^2(E_{CENAM-initial}) + u^2_{drift-TS}} \quad (3)$$

Where,

$$u_{drift-TS} = \frac{|E_{CENAM-initial} - E_{CENAM-final}|}{2\sqrt{3}} \quad (4)$$

7.2 Performance evaluation

In order to compare in a better way the measurement results, a normalized error equation criteria were used, (E_n). Since a correlation exists between INDECOPI and CENAM and also between LATU and CENAM, a modified equation will be used (equation 5), which takes into account the correlation due to direct calibration at CENAM [4].

$$E_n = \frac{E_{lab} - E_{ref}}{2\sqrt{u^2(E_{lab}) + u^2(E_{ref}) - 2u(E_{lab}, E_{ref})}} \quad (5)$$

Where,

E_n : Normalized error
E_{lab} : Laboratory's estimated error
E_{ref} : Reference error
$u(E_{lab})$: Laboratory's standard uncertainty
$u(E_{ref})$: Reference standard uncertainty
$u(E_{lab}, E_{ref})$: Covariance

The Covariance [5]:

$$u(E_{lab}, E_{ref}) = \sum_{i=1}^{N} \left[\frac{\partial E_{lab}}{\partial P_i} . \frac{\partial E_{ref}}{\partial P_i} . u^2(P_i) \right] \quad (6)$$

P_i : CENAM´s standards
$u(P_i)$: Standard uncertainty of CENAM's standards

The correlation term will only be used for the cases mentioned above (LATU and INDECOPI). The performance is determined by the normalized error according to the obtained values, where:

$$|E_n| \leq 1.0 \text{ Satisfactory result}$$

$$|E_n| > 1.0 \text{ Unsatisfactory result}$$

Table 4 and Figure 15 show the normalized error values for the participating laboratories with respect to the reference values.

Table 4. Participant laboratories normalized error results (equation 5) with respect to the reference values.

	700 kPa	1 400 kPa	2 100 kPa	2 800 kPa	3 500 kPa	4 200 kPa	4 900 kPa	5 600 kPa	6 300 kPa	7 000 kPa
INM	-0.2	-0.05	-0.05	-0.1	-0.2	-0.3	-0.4	-0.6	-0.7	-0.8
INACAL	-0.1	0.01	0.02	0.00	0.00	0.02	0.01	-0.05	-0.1	-0.04
ENAER	-0.8	-0.5	-0.4	-0.4	-0.5	-0.5	-0.6	-0.8	-0.9	-1.0
LACOMET	0.3	0.3	0.2	0.2	0.1	-0.03	-0.1	-0.2	-0.3	-0.5
LATU	0.1	-0.02	0.02	0.03	-0.1	-0.1	0.01	0.00	0.1	0.1

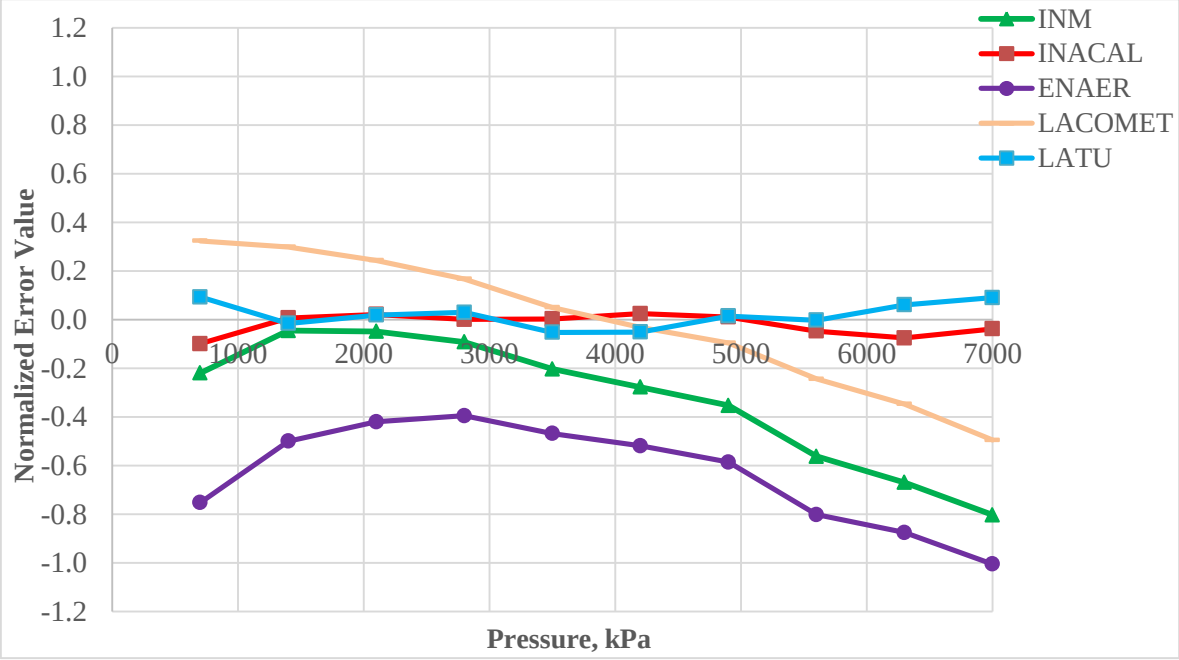

Figure 15. Participant laboratories normalized error results in the range from 700 kPa to 7 000 kPa.

8. CONCLUSIONS AND RECOMMENDATIONS

The comparison had no significant inconveniences, the activities program was implemented as scheduled. This comparison had the participation of 4 Sistema Interamericano de Metrología (SIM) subregions (NORAMET, CAMET, ANDIMET, SURAMET).

The transfer standard had a drift; however the drift was not big and did not affect the comparison results. On the other hand, the drift was included as part of the comparison reference uncertainty values. The transfer standard was suitable for the purposes of this comparison.

The results obtained by the normalized error equation analysis demonstrated that there is a good compatibility among the participating laboratories in the calibration of a high accuracy digital manometer within the gauge pressure range from 700 kPa to 7 000 kPa.

The greatest difference in error values belongs to ENAER (Chile). However, the uncertainty assigned by ENAER to the transfer standard makes ENAER results compatible with the reference values and those obtained by the other participants.

In conclusion, all the participating laboratories' results are compatible with the comparison established reference values; which allows to obtain participating NMI's CMCs technical support.

9. ACKNOWLEDGEMENTS

We want to give special thanks to the Centro Nacional de Metrologia de Mexico (CENAM) for its contribution to carry out this comparison successfully. We also wish to thank all the participating NMIs, especially the metrologists who made the measurements and calculations.

10. REFERENCES

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