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PRESSURE STANDARDS COMPARISON WITHIN THE INTERAMERICAN METROLOGY SYSTEM (SIM), UP TO 100 MPa.

Speaker.
Torres Guzmán J. C.
Centro Nacional de Metrología
km 4,5 carretera a Los Cués, El Marqués, Querétaro C.P. 76 241, Mexico
Tel. (52) 4 211 0572, Fax (52) 4 211 0578, e-mail jtorres@cenam.mx

Paper Authors.
Jorge C. Torres Guzmán, Benjamín Soriano Cardona CENAM, Mexico
Paulo R. Couto INMETRO, Brazil

Abstract. A pressure comparison was carried out within the Interamerican Metrology System (SIM), in order to estimate the level of agreement for the realization of the quantity and the uncertainty associated to its measurement. The comparison participants were at least, one National Metrology Institute (NMI) from each of the five SIM areas. The comparison was carried out up to 100 MPa, using an electronic comparison standard with $1 \cdot 10^{-4}$ of full-scale accuracy. The Centro Nacional de Metrología, CENAM, in Mexico, was the coordinator and pilot laboratory. The results obtained the deviations graphs that include the uncertainty for each participating laboratory are presented in this document.

1. Introduction

The realization of the PRESSURE quantity is a task assigned to the pressure laboratories of the National Metrology Institutes (NMI), which are in charge of the correct dissemination of this quantity as well as giving the adequate levels of uncertainty to the traceability chain, according to the country’s needs. Within the frame of international cooperation in the Interamerican Metrology System (SIM), a comparison was carried out in order to estimate the level of agreement for the realization of the quantity of pressure, and the uncertainty associated to its measurement. The comparison was performed among laboratories using similar standards (piston gages, also known as pressure balances). The SIM country members have always had a keen interest in comparing their capabilities to realize the quantity of pressure. Until now, a full pressure comparison within the SIM countries had not been performed. This comparison was carried out for up to 100 MPa (oil) and at least one national laboratory from each of the five areas of SIM participated.

2. Scope of work

The ISO publication "International Vocabulary of Basic and General Terms of Metrology" (VIM)[1], and the International System of Units[2], SI, were used for the comparison and for the writing of this document. The recommendations established in the Guide to the Expression of Uncertainty in Measurement[3], were followed for the uncertainty evaluation.

2.1 Program objectives

This comparison of pressure standards differs from other similar comparisons[4,5] in several aspects. One of them is that this comparison is the first part of two, as both of them have the same measurement range; this comparison was held with an electronic transfer standard as the comparison standard, the second part uses a pressure balance. Another aspect is the preparation and use of a complete set of documents that include: a) general guidelines[6]; b) measurement instructions for the calibration of the comparison standard[7] to avoid the introduction of errors due to poor knowledge of the comparison standard; c)data sheet[8] to understand and interpret adequately data and results. This comparison was carried out in less than 9 months, which meant a compromise of each laboratory to the comparison.

2.2 Participating laboratories

There were seven participating NMIs which are listed in table 1. The table presents the laboratories according to the SIM areas where they belong. The Centro Nacional de Metrología, CENAM, acted as the coordinator and pilot laboratory.

SIM area	Laboratory	Person in charge	Country
Suramet	Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (INMETRO) Centro de Física, Instituto Nacional de Tecnología Industrial (INTI)	Paulo R. Couto Juan Forastieri	Brazil Argentina
Andimet	Centro de Control de Calidad y Metrología, Superintendencia Industria y Comercio (SIC)	Roberto Idrovo	Colombia
Camet	Oficina Nacional de Normas y Unidades de Medida (ONNUM)	Gerardo Padilla	Costa Rica
Carimet	Jamaica Bureau of Standards (JBS)	Allan Foreman	Jamaica
Noramet	National Institute of Standards and Technology (NIST) Centro Nacional de Metrología (CENAM)	Douglas Olson Jorge C. Torres	USA Mexico

***Table 1**. Participating laboratories.*

2.3 Comparison standard

Table 2 shows the information of the comparison standard used, as it was provided by the manufacturer[9].

Transducer Type:	Oscillating quartz crystal
Range:	10 MPa to 100 MPa
Units:	kPa
Resolution:	0,1 kPa
Accuracy Class:	0,01%
Predicted stability	0,009% in 1 year
Uncertainty:	0,004% of full scale
Make:	DH Instruments
Model:	RPM3 A15000-L
Serial number or Identification:	588

***Table 2.** Comparison standard data.*

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2.4 Comparison rounds

The comparison was performed in three rounds, each one included initial and final measurements on the pilot laboratory. The rounds were designed according to the geographical location of the laboratories to avoid excessive handling of the comparison standard and to shorten the time consumed for its transportation.

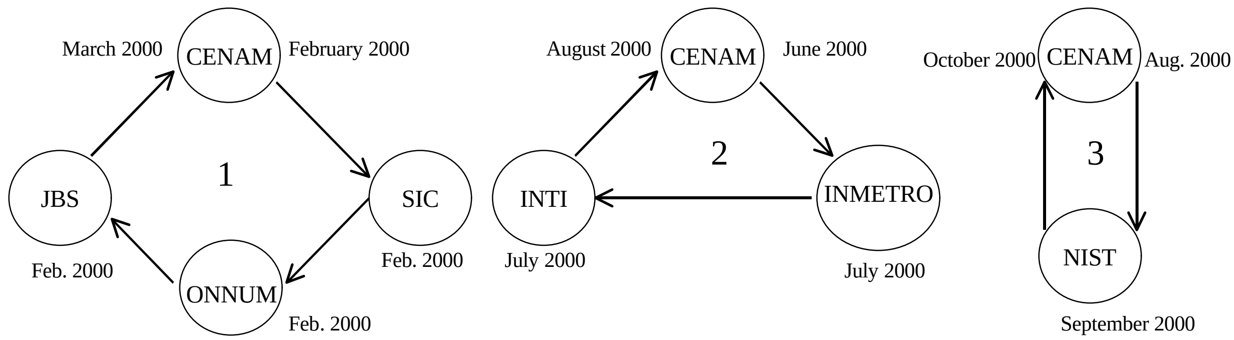

Figure 1. *Comparison rounds.*

2.5 General guidelines and procedure

The general guidelines and procedure for the comparison were established in the three documents[6,7,8] described in 2.1; those documents are based on the Guidelines for key comparisons by Terry Quinn[10]. Just a few relevant aspects of the measurement protocol are mentioned in this paper:

a) It was recommended that the comparison standard was connected to the power supply in the place where it was going to be calibrated and the default settings (normal operation settings) were checked and entered 24 hours before starting the measurement procedure, for both, warming up and stabilization.

b) The comparison standard was set to zero before the calibration began and after each loop. The first “zero” setting entered the local atmospheric pressure as the reference pressure, the following “zero” setting permitted to diminish the influence of the zero drift.

c) The measurements on the comparison standard were performed in three loops, each loop had two series (one ascending and one descending). In each series, ten points were measured, from 10 MPa up to 100 MPa (in 10 MPa increments). A total of 60 measurements were done for the complete comparison in each laboratory.

d) After finishing the corresponding readings, each participating laboratory sent to the pilot laboratory, the complete data file report of the measurements, including the associated uncertainty.

e) The technical staff of each participating laboratory performed the measurements and it was their sole responsibility to fulfil the requirements of the agreed regulating documents of this comparison.

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3. Participating laboratories' standards

All participating laboratories used piston gages as their standard for this comparison. The information of the laboratories' standards is presented in table 3.

	Laboratory						
	SIC	JBS	ONNUM	INMETRO	INTI	CENAM	NIST
Piston-cylinder material	Tungsten carbide, stainless steel	Stainless steel	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide	Tungsten carbide
Piston-cylinder design	Free deformation	Inner unit of dual concentric piston-cylinder	Double piston, simple cylinder	Free deformation	Free deformation	Free deformation	Re-entrant
Range	0,2 MPa to 140 MPa	Up to 110 MPa	2 MPa to 120 MPa	1 MPa to 250 MPa	5 MPa to 100 MPa	1 MPa to 100 MPa	7 MPa to 100 MPa
Relative uncertainty (k=2, %R)	$30 \cdot 10^{-6}$ + $0,2 \cdot 10^{-6}$/MPa	$120 \cdot 10^{-6}$	$230 \cdot 10^{-6}$	$54 \cdot 10^{-6}$	$45 \cdot 10^{-6}$	$31 \cdot 10^{-6}$	$37 \cdot 10^{-6}$
Traceability	NPL, UK	PTB, Germany	NPL, UK	PTB, Germany	PTB, Germany	CENAM	NIST
Date	2000 02 07	1998	2000 02 14	2000 07 13	1999	2000 03 28	2000
gl m/s^2	9,773 867	9,785 01	9,779 049 9	9,787 487	9,797 05	9,780 845	9,801 011
Effective area, m^2	$4,035\ 05 \cdot 10^{-6}$	$4,032\ 22 \cdot 10^{-6}$	$4,032\ 3 \cdot 10^{-6}$	$1,961\ 31 \cdot 10^{-6}$	$9,805\ 45 \cdot 10^{-6}$	$9,805\ 18 \cdot 10^{-6}$	$16,802\ 57 \cdot 10^{-6}$

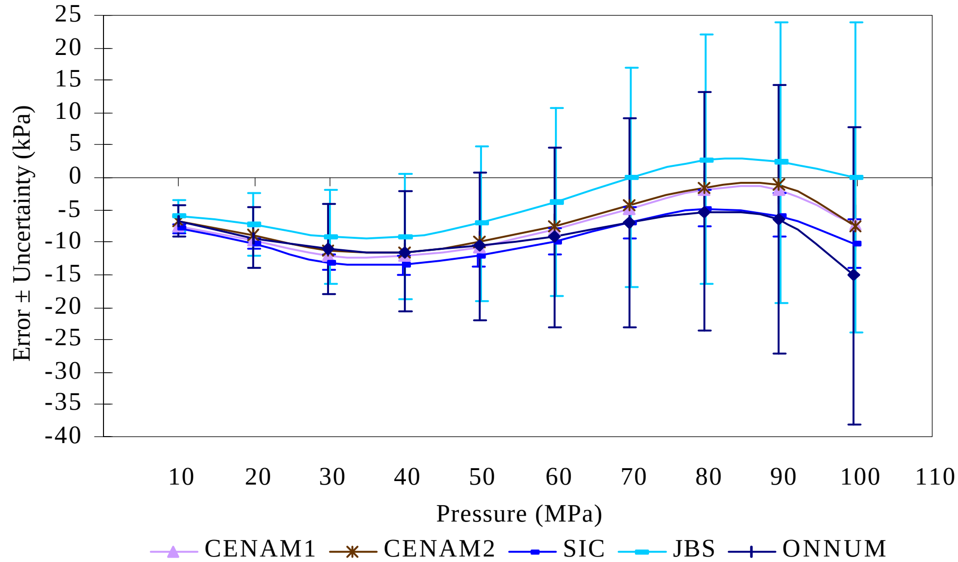
Table 3. *Participating laboratories' standards.*

4. Results

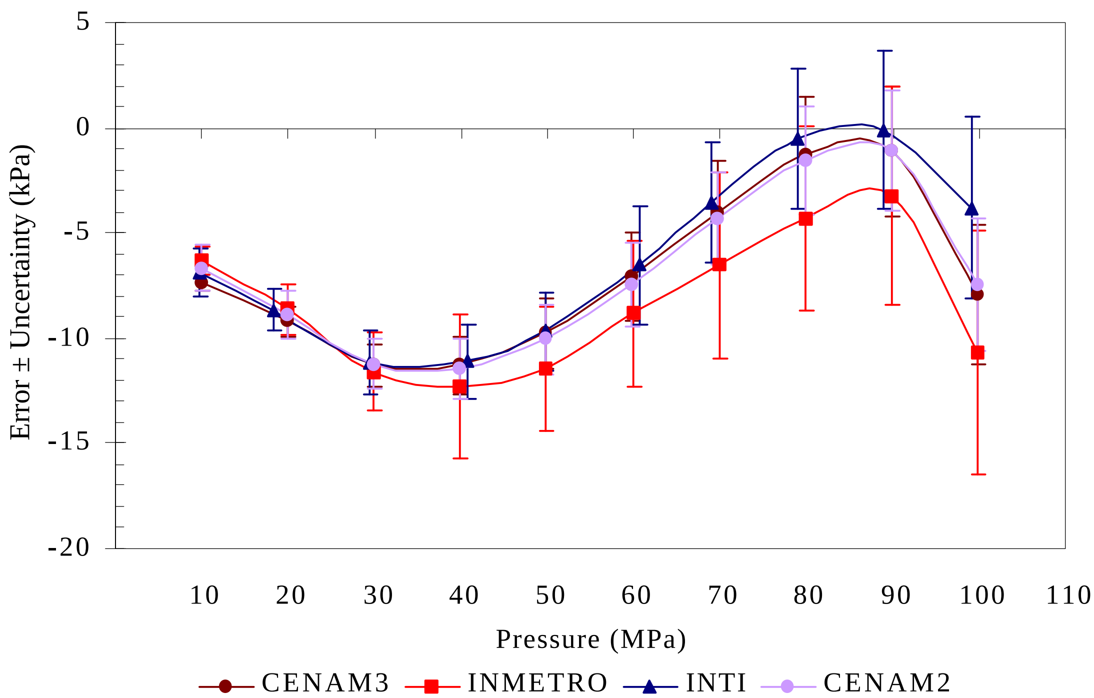
The results of the measurements made by the participating laboratories were entered into the data file provided for the comparison[8] and sent to the coordinating laboratory. The uncertainties calculated by each laboratory were based mainly on three contributing elements: the standard used by the laboratory, repeatability and resolution of the comparison standard (instrument); though, each laboratory made all the corresponding corrections to the measured pressure and included some other contributing quantities into the uncertainty evaluation.

The resulting graphs, showing the error and uncertainty estimated for the instrument by each laboratory, are presented in this section. These graphs are based in a linearity assumption of the instrument response and the least squares best-fit line has been superimposed for each laboratory final measurement results.

The following first three graphs present the results of the comparison rounds (as described in 2.4) and include the errors and uncertainties. In graph 4 all the laboratories final measurement results are included, but does not show the uncertainties, this is with the purpose of increasing visibility and clarity.



***Graph 1.** Results (estimated error and uncertainty) from the laboratories in the first comparison round.*



***Graph 2.** Results from the laboratories in the second comparison round.*

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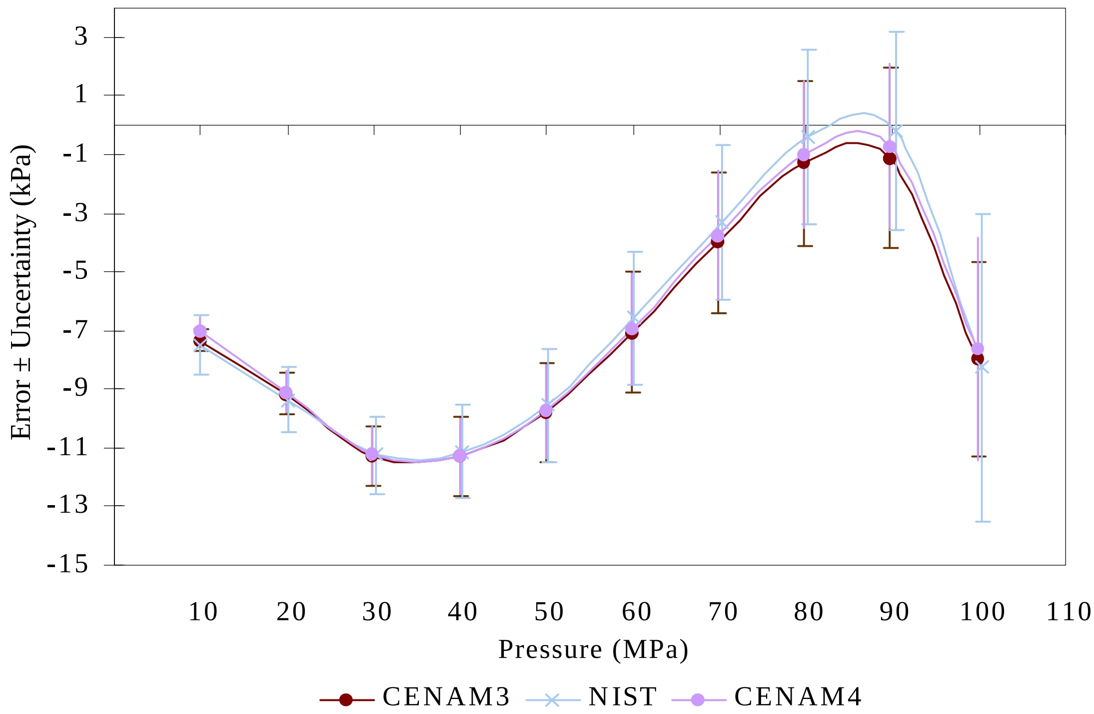
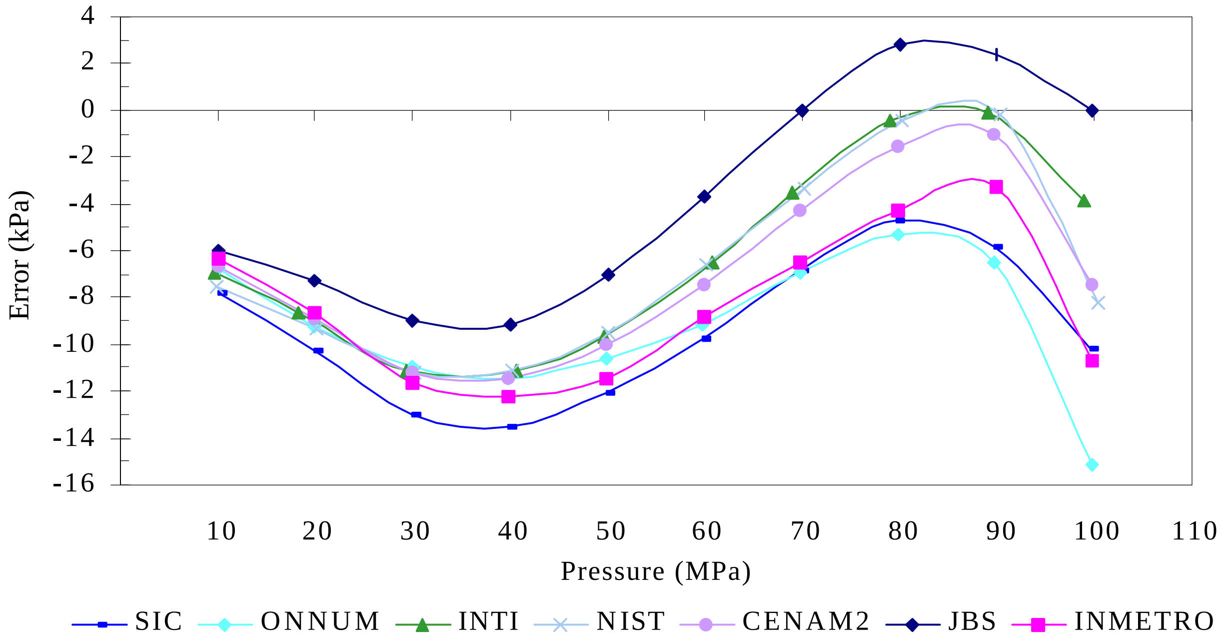
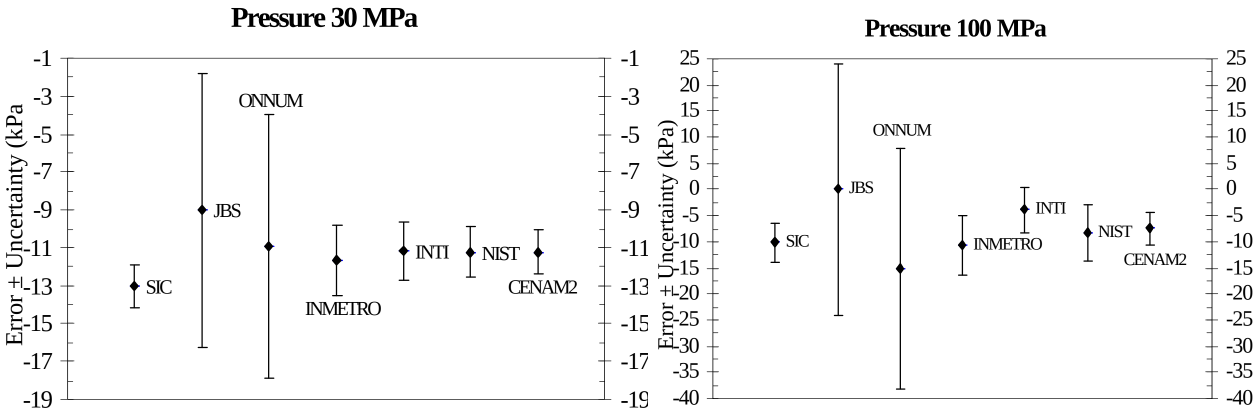


Graph 3. *Results from the laboratories in the third comparison round.*



Graph 4. *Results (error only) from all the participating laboratories.*

Graphs presenting the error and uncertainty of each laboratory for an applied pressure are included in graph 5. The pressures selected are the ones that presented bigger differences (dispersion).



Graph 5. *Error and uncertainty comparison, for a given pressure (30 MPa and 100 MPa), of all participating laboratories.*

5. Discussion

As it is shown in graph 5, the biggest difference (which is at 30 MPa) is between SIC and the group formed by CENAM, NIST and INTI, where the uncertainties of these laboratories barely overlap each other.

In order to compare in a better way the measurement results from the participating laboratories, a normalized error was obtained for the results of all laboratories using a modified equation of the one described in NORAMET´s document 8[11] and SEA–2/03[12]. The equation used here (equation 1) takes into account the results from all laboratories and its aim is to compare all laboratories with a general average in one graph. As the real pressure values differ for each laboratory, the estimated error is considered instead of using a pressure lecture. Additionally, the reference values used in the equation are the average error and the combined uncertainty obtained from all the participating laboratories.

$$e_n = \frac{e_{lab} - e_{avg}}{\sqrt{U_{lab}^2 + U_{avg}^2}} \tag{1}$$

Where, e_n - normalized error
e_{lab} - laboratory's estimated error
e_{avg} - average estimated error (for all participating laboratories)
U_{lab} - laboratory's expanded uncertainty
U_{avg} - average expanded uncertainty (see equation 2)

$$U_{avg} = \sqrt{U_{lab1}^2 + U_{lab2}^2 + ... + U_{labn}^2} \tag{2}$$

Where, $U_{lab1...n}$ - expanded uncertainty declared by each laboratory (from 1 to 7)

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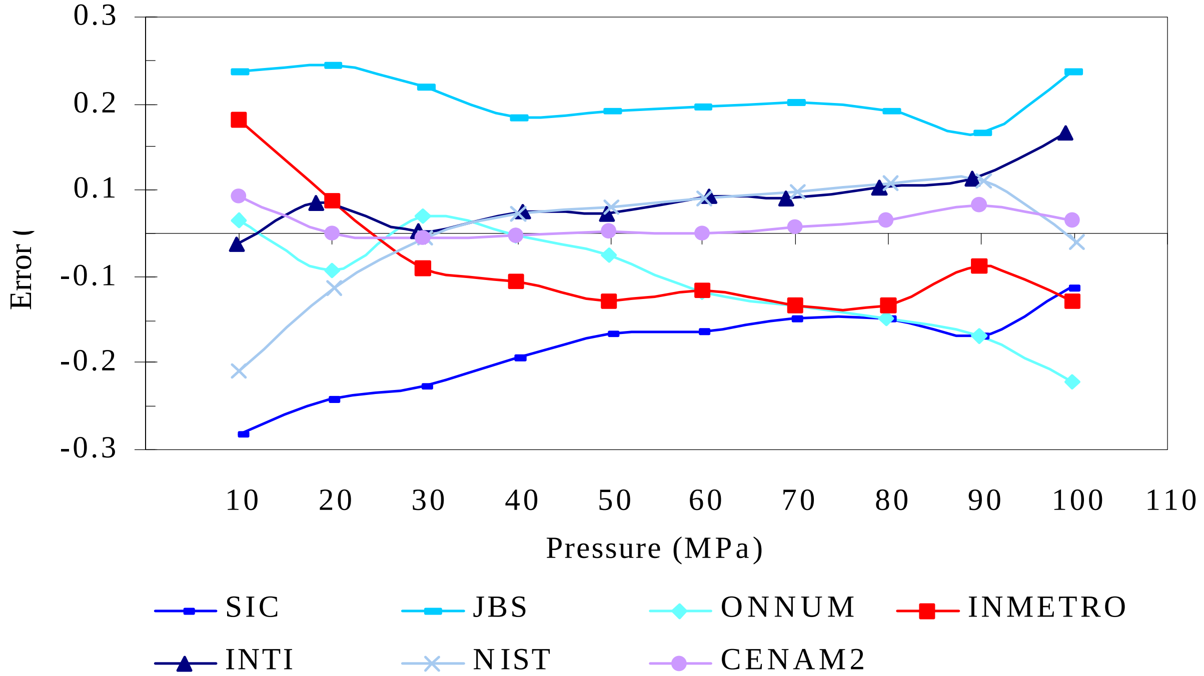
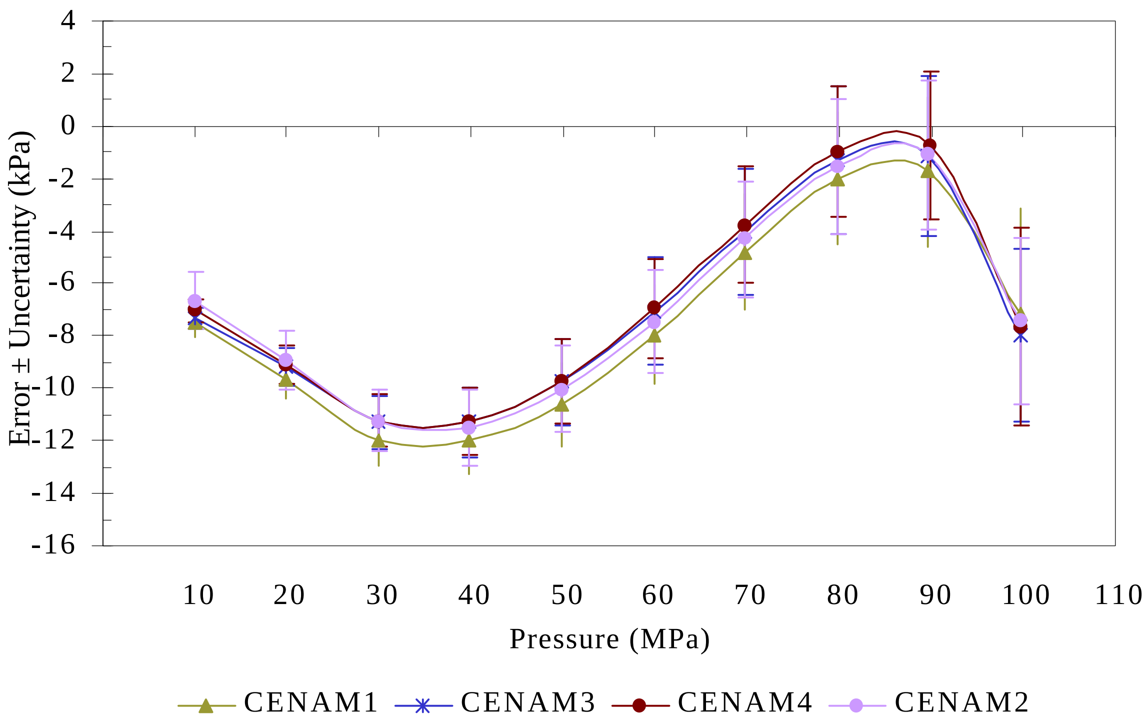


Graph 6. *Results of the comparison using the normalized error equation.*

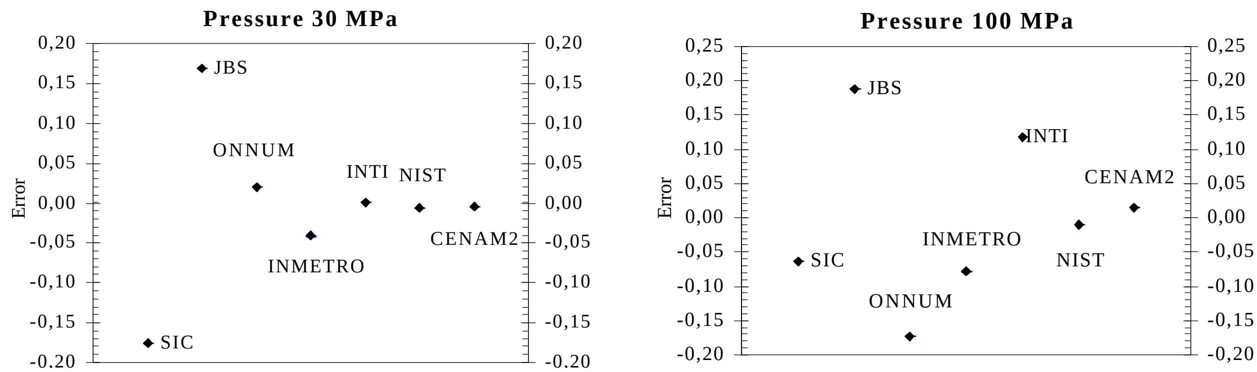
The pilot laboratory made a stability study of the comparison standard. The 4 full calibrations made at CENAM were analyzed to assess the stability of the instrument and the different measurement results are presented as follows.



Graph 7. *Results from the 4 calibrations of the comparison standard made at CENAM.*

A very small time dependant variation on the instrument's response was detected, as it is shown in graph 7. This drift seems to be pressure dependent too. To compensate this effect, a no linear correction would have to be made; as the maximum drift during the complete period of the comparison is less than $10\ 10^{-6}$ (relative to the applied pressure) the correction of this effect is unnecessary.

Graph 8 shows the same error and uncertainty comparison of all laboratories (graph 5) but uses the normalized error results.



Graph 8. *Error, for a given pressure (30 MPa and 100 MPa), of all participating laboratories using the normalized error equation.*

When using the normalized error approach, the scatter or dispersion on the estimated error is reduced greatly and the metrological equivalence of measurements is more apparent.

6. Conclusion

Seven national laboratories (INMETRO, INTI, SIC, ONNUM, JBS, NIST and CENAM) compared their pressure standards by means of an electronic transducer without performing preliminary measurements prior to the reported data.

The transducer is not a typical client’s transducer received for calibration and its response was such as to challenge the measurement capability, even of experienced operators. In general, the results demonstrate agreement among the seven laboratories with negligible differences observed.

It is important to notice the differences on uncertainties declared among laboratories (the maximum difference is more than 7 times) and even with those differences, all laboratories were able to observe the same nonlinear behavior of the transducer.

The normalized error equation employed has been proposed as means of assessing comparability among laboratories and certainly needs a deeper study to validate its applicability and usefulness. There are other attempts made to compare results from comparisons[13].

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