Bilateral Comparison in the Calibration of Atmospheric Tank Provers by Volumetric and Gravimetric Methods

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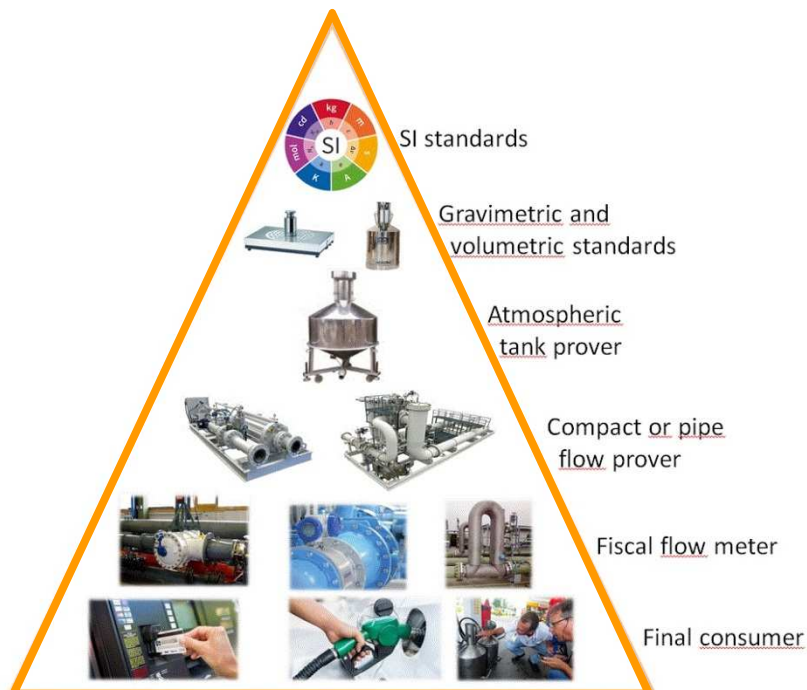
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1. Introduction

Atmospheric tank provers are measurement standards used in the calibration of liquid volume provers. These provers are used in the calibration of oil flow meters for fiscal, allocation and custody transfer measurements. Tank provers are also used in the verification of volume totalizers of liquid fuels in gas stations.

SI standards

Gravimetric and volumetric standards

Atmospheric tank prover

Compact or pipe flow prover

Fiscal flow meter

Final consumer

To provide traceability in the measurement of liquid products tank provers must have their volumes determined with **accuracy** and **reliability** by means of a proper calibration.

1. Introduction

In turn, the satisfactory participation of calibration laboratories in proficiency testing activities and in other types of interlaboratorial comparisons consists in a mechanism established by the ISO/IEC 17025 standard for the laboratories to ensure the validity of their measurement results.

2. Bilateral interlaboratory comparison

Under a common interest and agreement, the Institute for Technological Research (IPT) and the Weights and Measures Institute of the State of Sao Paulo (IPEM-SP) planned and carried out a bilateral interlaboratory comparison in the calibration service of atmospheric tank provers.

Institute for Technological Research
of the State of São Paulo (IPT)

Weights and Measures Institute
of the State of Sao Paulo (IPEM-SP)

Both IPT and IPEM are public laboratories accredited by the Cgcre-General Coordination of Accreditation (the Brazilian ILAC member laboratory accreditation body).

2. Bilateral interlaboratory comparison

The tank provers used in the comparison

Tank prover of 20 L

Tank prover of 1 000 L

Stainless steel atmospheric tank prover of 20 L, with carrying handle, identification number IE-02361, indication interval of ±200 cm³ and resolution of the scale of 20 cm³.

Stainless steel atmospheric tank prover of 1 000 L, mounted on tripod, ball drain valve for discharge, identification number IE-09644, indication interval of ±15 L and resolution of the scale of 0.5 L.

2. Bilateral interlaboratory comparison

Calibrated scale points

Calibrations were performed in three points of the tank provers scales: the zero point corresponding to the nominal volume of the tank prover, an upper point and a lower point.
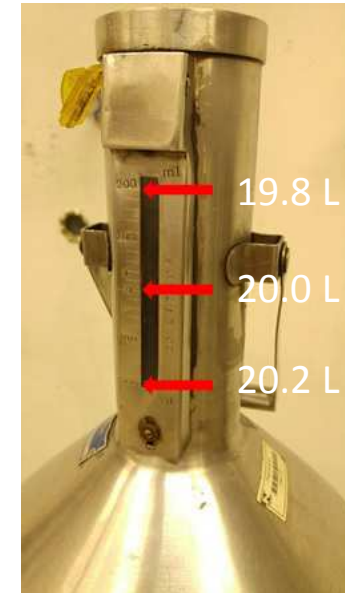
19.8 L
20.0 L
20.2 L

Tank prover of 20 L

Scale point	20 L tank prover		1 000 L tank prover	
	Scale mark	Nominal volume	Scale mark	Nominal volume
Lower	-200 mL	19.8 L	-10 L	990 L
Zero	0 mL	20.0 L	0 L	1 000 L
Upper	+200 mL	20.2 L	+10 L	1 010 L

990 L
1 000 L
1 010 L
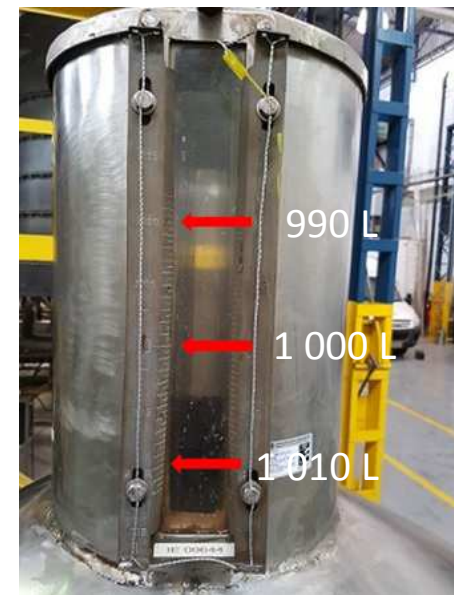
Tank prover of 1 000 L

3. Calibration methods

For the calibration of the tank provers each laboratory used its own method of calibration and calculation of results and uncertainties

IPEM-SP used the volumetric method and IPT used the gravimetric method of static weighing of the water contained in the tank prover.

Volumetric method

IPEM

Calibration of an atmospheric tank prover by volumetric method consists on transfers of water from standard volume measures from which the transferred volume and its measurement uncertainty required for calibration is known.

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3.1 Volumetric method

**Measurements on the neck scale reading of zero of the tank provers**

For the 1 000 L tank prover calibration, a standard volume measure with nominal volume of 100 L was used ten times in order to transfer about 1 000 L of water into it.
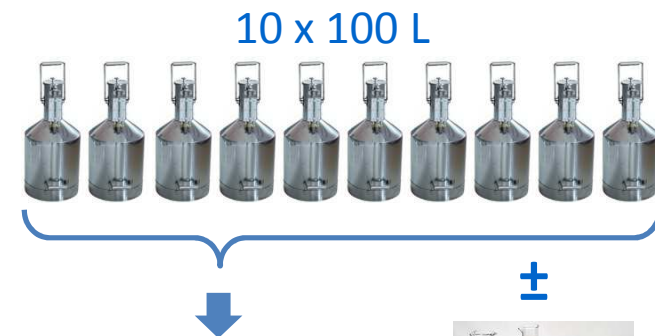
For the 20 L tank prover calibration, a standard volume measure with nominal volume of 20 L was used once.

10 x 100 L

±

Standard glasswares

1 x 20 L

±

Standard glasswares
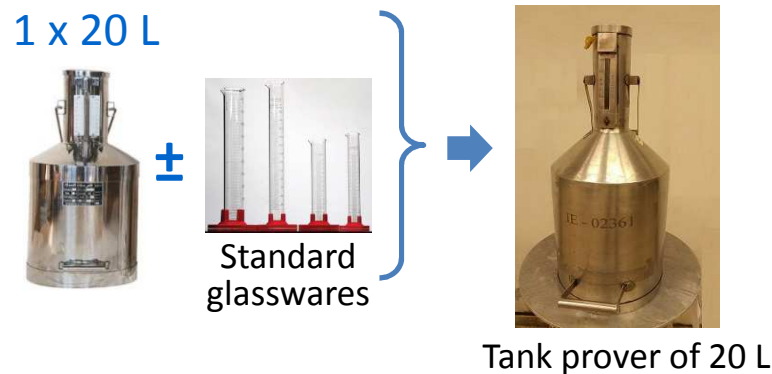
Tank prover of 20 L

Tank prover of 1 000 L
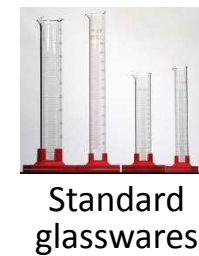
The meniscus of water in both tank provers were adjusted to the respective zero point of the scale using standard glasswares.

3.1 Volumetric method

Measurements on the upper point

Since the zero point was measured, standard glasswares were used to provide more water into each tank prover until the meniscus of water reaches the chosen upper point of the scale. So its volume is calculated from the reference volume determined at zero point plus the volumes transferred using the standard glasswares.

Tank prover of 20 L

Tank prover of 1 000 L

3.1 Volumetric method

Measurements on the lower point

Once the volume of upper point is calculated, standard glasswares were used to remove water from each tank prover until the meniscus of water reaches de chosen lower point. Thus the volume of lower point is calculated by the volume determined on the upper point minus the volume of water removed using the standard glasswares.
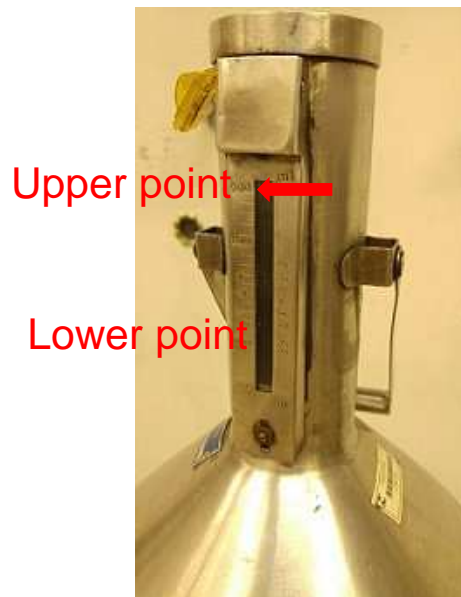
Tank prover of 20 L

Tank prover of 1 000 L

3.1 Volumetric method

For each point measured, the temperature of water is determined using a digital thermometer.

Once the measurements of the three points are finished, the steps described previously are repeated twice in order to determine the average volumes and the associated uncertainties.

Environmental parameters

Tank prover	Water temperature (°C)	Air temperature (°C)	Relative humidity (%)
1 000 L	19,1 ± 0,6	19,8 ± 0,4	63,7 ± 2,9
20 L	20,0 ± 0,2	19,7 ± 0,2	61,6 ± 1,4

The stability of the water temperature is a key factor for the success of the calibration. So, the water temperature during calibration should remain as stable as possible with a maximum difference between the ambient air temperature and the water temperature of ±1 °C.

3.1 Volumetric method

Corrections on the volume determinations

Temperature is able to modify the volume of liquids and containers. The volume of a tank prover is usually referred as it is used at 20 °C. Since the calibrations are generally performed at temperatures other than 20 °C, the measured volumes must be corrected to 20 °C as follows:

$$V_{Pt1} = V_{P20}.[1 + \gamma_P.(t_1 - 20)] \qquad (1)$$

$$V_{ob20} = V_{Pt1}.[1 - \gamma_{ob}.(t_2 - 20)] \qquad (2)$$

where:

V_{Pt1} : liquid volume in the standard at temperature t_1;

V_{P20} : liquid volume in the standard at 20 °C;

V_{ob20} : corrected liquid volume on the object at 20 °C;

t_1 : water temperature on the standard;

t_2 : water temperature on the tank prover;

γ_P : thermal expansion coefficient of the standard;

γ_{ob} : thermal expansion coefficient of the tank prover.

3.1 Volumetric method

Main sources of measurement uncertainties

> Standard deviation of volume measurements

> Uncertainties associated to the standard volumes measures

> Uncertainties associated to the glasswares volumes

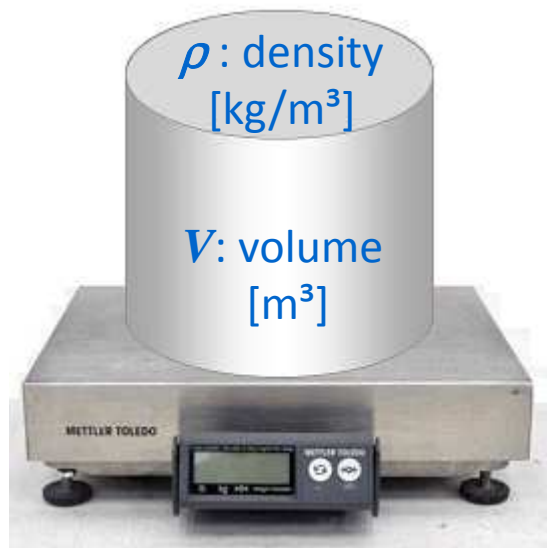> Uncertainties associated to the water temperatures

Tank prover volume

Uncertainties were calculated according to the ISO GUM.

3.2 Gravimetric method

ρ : density [kg/m³]

V: volume [m³]

m: mass [kg]

The gravimetric method used by IPT is based on the static weighing of the mass of water contained in the tank prover using an electronic scale.

The reference volume (V) is determined from the value of the measured mass (m) of water and its density (ρ) at measuring conditions.

At IPT, calibrations of tank provers with volumetric capacity up to 500 L is carried out in a single weighing. For vessels of capacities above 500 L, calibration is performed by means of multiple weighings.

3.2 Gravimetric method

Calibration assembly

Calibration of the 20 L tank prover

Calibration by direct comparison between the volume of water collected in the prover and the mass of water measured using an electronic scale.

Tank prover was carefully filled with water to the point of the scale to be calibrated.

The water density at the calibration temperature was used to determine the tank prover volume.

Destilled water supply

Graduated scale

Meniscus

20 L tank prover

Electronic scale

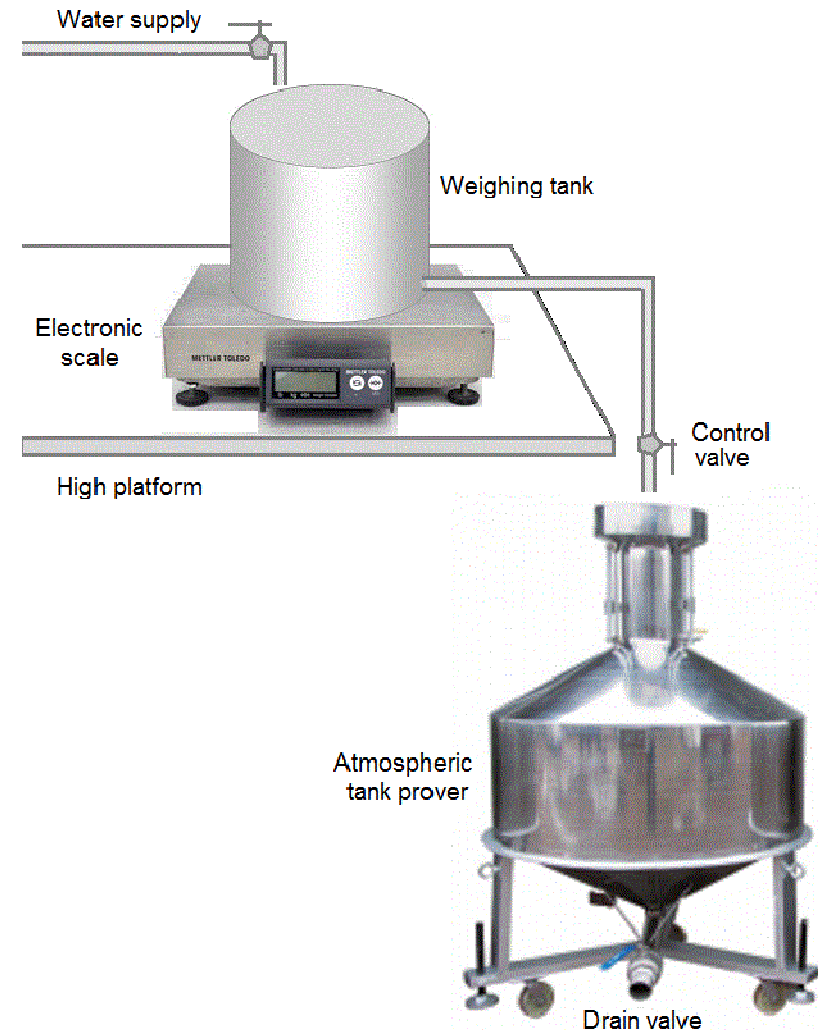**Schematic for calibration of the 20 L tank prover**

3.2 Gravimetric method

Calibration of the 1 000 L tank prover

Calibration by direct comparison between the volume of water collected in the prover and the delivered mass of water measured using an electronic scale.

Tank prover was carefully filled with water supplied from a weighing tank to the point of the scale to be calibrated.

The water density at the calibration temperature was used to determine the tank prover volume.

Water supply

Weighing tank

Electronic scale

High platform

Control valve

Atmospheric tank prover

Drain valve

Schematic for calibration of the 1 000 L tank prover

3.2 Gravimetric method

Calculation Methodology

The volume of water contained in the tank prover by the gravimetric method is determined using the following equation:

$$V_{\text{water}} = \frac{m_{\text{water}}}{\rho_{\text{water}}}$$

ρ : density [kg/m³]

V: volume [m³]
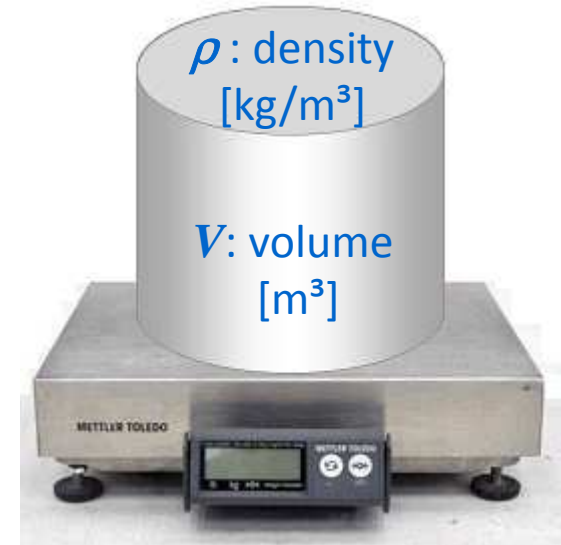
m: mass [kg]

where:

V_{water} : volume of water contained in the tank prover [m³];

m_{water} : mass of water measured by the scale [kg];

ρ_{water} : density of the water in the tank prover temperature [kg/m³].

3.2 Gravimetric method

Calculation Methodology

- *Correction of the **apparent initial mass** indicated on the scale according to its calibration certificate*

$$m_{\text{init\_ind\_corr}} = m_{\text{init\_ind}} + k_1$$

where:

$m_{\text{init\_ind\_corr}}$: initial mass indicated on the scale and corrected by its
    calibration certificate [kg]

$m_{\text{init\_ind}}$: initial mass indicated on the scale [kg]

k_1 : initial mass correction value, obtained from the scale
    calibration certificate [kg]

The method of calculating the **apparent final mass** indicated on the scale follows the same procedure.

3.2 Gravimetric method

● *Determination of the **initial reference mass***

Correction of apparent initial mass of water for **air buoyancy effect**:

$$m_{init\_refer} = (m_{init\_ind\_corr}) \cdot \frac{\rho_{water\_scale} \cdot (\rho_{std\_mass} - \rho_{air\_scale\_cal})}{\rho_{std\_mass} \cdot (\rho_{water\_scale} - \rho_{air\_tank\_cal})}$$

where:

m_{init_refer} : initial reference mass [kg]

ρ_{water_scale} : density of the water at the temperature inside the weighing tank [kg/m³]

ρ_{std_mass} : density of the standard mass used in the calibration of the scale
[8 000 kg/m³]

$\rho_{air\_scale\_cal}$: density of the ambient air during calibration of the scale [1.2 kg/m³]

$\rho_{air\_tank\_cal}$: density of the ambient air during tank prover calibration [kg/m³]

The method of calculating the **final reference mass** follows the same procedure.

3.2 Gravimetric method

- *Determination of the **net reference mass** of water*

$$m_{\text{ref}} = m_{\text{final\_refer}} - m_{\text{init\_refer}}$$

where:

m_{ref} : reference mass of water [kg]

$m_{\text{final\_refer}}$: final reference mass [kg]

$m_{\text{init\_refer}}$: initial reference mass [kg]

3.2 Gravimetric method

● **Density of water** *used in tank prover calibration*

Calibration of the 20 L tank prover was performed using <u>distilled water</u>. Density of the distilled water used to convert the mass of water to an equivalent volume of the liquid is given by the following state equation:

$$\rho_{\text{dist\_water}} = 999,8395639 + 0,06798299989 \cdot T_{\text{tank}}$$
$$- 0,009106025564 \cdot T_{\text{tank}}^{2} + 0,0001005272999 \cdot T_{\text{tank}}^{3}$$
$$- 0,000001126713526 \cdot T_{\text{tank}}^{4} + 0,000000006591795606 \cdot T_{\text{tank}}^{5}$$

where:

T_{tank} : water temperature at the tank prover temperature [°C]

$\rho_{\text{dist\_water}}$: density of water at the tank prover temperature [kg/m³]

Calibration of the 1 000 L tank prover was carried out using <u>clean tap water</u> and its density was determined using a calibrated density meter.

3.2 Gravimetric method

- *Determination of **the tank prover reference volume** at the calibration temperature*

Reference volume of the tank prover at the calibration temperature is calculated using the following equation:

$$V_{\text{refer}} = \frac{m_{\text{refer}}}{\rho_{\text{water\_tank}}}$$

where:

V_{refer} : reference volume at tank prover temperature [m³]

$\rho_{\text{water\_tank}}$: water density at the tank prover temperature [kg/m³]

3.2 Gravimetric method

• *Calculation of the **volume of the tank prover** referred to the temperature of 20 °C*

Reference volume of the tank prover at the calibration temperature is calculated using the following equation:

$$V_{20\ ^{\circ}\text{C}} = \frac{V_{\text{refer}}}{CTS}$$

where:

$V_{20\ ^{\circ}\text{C}}$: volume of the tank prover at the reference temperature of 20 °C [L]

V_{refer} : volume of the tank prover at the tank prover temperature [m³]

CTS : correction factor by thermal expansion of the tank prover material

3.2 Gravimetric method

- *Correction factor by thermal expansion of the tank prover material (CTS)*

$$CTS = 1 + G_c \cdot (T_{tank} - 20)$$

where:

CTS : thermal expansion correction factor of the tank prover material
G_c : volumetric thermal expansion coefficient of the tank prover material [1/ °C]
T_{tank} : tank prover temperature [°C]
20 : reference temperature of 20 °C

3.2 Gravimetric method

• *Measurement bias calculation*

$$E = 100 \cdot \left(\frac{V_{\text{nom\_vol}} - V_{\text{refer (20 °C)}}}{V_{\text{refer (20 °C)}}} \right)$$

where:

E : measurement bias of volume indication of the tank prover [L];

$V_{\text{refer (20 °C)}}$: reference volume of tank prover corrected for the reference condition of 20 °C [L];

$V_{\text{nom\_vol}}$: volume indicated on the mark scale [L].

4. Calibration results

Table 1: Results of IPEM-SP for calibration of 20 L tank prover.

(Mark scale) Nominal volume (L)	Reference volume (L)	Measurement bias (L)	Expanded uncertainty (L)	Coverage factor *k*
(-02) 19,8	19,805	-0,005	0,005	2,0
(0) 20,0	20,003	-0,003	0,005	2,0
(+0,2) 20,2	20,202	-0,002	0,005	2,0

Table 3: Results of IPEM-SP for calibration of 1 000 L tank prover.

(Mark scale) Nominal volume (L)	Reference volume (L)	Measurement bias (L)	Expanded uncertainty (L)	Coverage factor *k*
(-10) 990	989,79	0,21	0,12	2,0
(0) 1 000	1 000,04	-0,04	0,12	2,0
(+10) 1 010	1 010,48	-0,48	0,12	2,0

Table 2: Results of IPT for calibration of 20 L tank prover.

(Mark scale) Nominal volume (L)	Reference volume (L)	Measurement bias (L)	Expanded uncertainty (L)	Coverage factor *k*
(-02) 19,8	19,804	-0,004	0,012	2,02
(0) 20,0	20,004	-0,004	0,012	2,02
(+0,2) 20,2	20,204	-0,004	0,012	2,02

Table 4: Results of IPT for calibration of 1 000 L tank prover.

(Mark scale) Nominal volume (L)	Reference volume (L)	Measurement bias (L)	Expanded uncertainty (L)	Coverage factor *k*
(-10) 990	989,7	0,3	0,4	2,03
(0) 1 000	1 000,1	-0,1	0,4	2,03
(+10) 1 010	1 010,5	-0,5	0,4	2,03

5. Evaluation of the results

The evaluation of the performance of the participants in the interlaboratory comparison was performed using the normalized error (NE) criterion calculated for the measurement bias parameter, according to the expression:

$$NE = \left| \frac{E_{\text{IPEM}} - E_{\text{IPT}}}{\sqrt{U_{\text{IPEM}}{}^2 + U_{\text{IPT}}{}^2}} \right|$$

where:

E_{IPEM} : result obtained by IPEM-SP laboratory;

E_{IPT} : result obtained by IPT laboratory;

U_{IPEM} : expanded uncertainty associated to the results of IPEM-SP laboratory;

U_{IPT} : expanded uncertainty associated to the results of IPT laboratory.

5. Evaluation of the results

Results of the evaluation of normalized error obtained in the comparison of the results of the calibrations carried out by IPEM-SP and IPT for the tank provers of 20 L and 1 000 L.

Table 5: Normalized error for the results of 20 L tank prover.

(Mark scale) Nominal volume (L)	Difference between measurement bias values (L)	Normalized error *NE*
(-02) 19,8	-0,001	0,08
(0) 20,0	0,001	0,08
(+0,2) 20,2	0,002	0,15

Table 6: Normalized error for the results of 1 000 L tank prover.

(Mark scale) Nominal volume (L)	Difference between measurement bias Values (L)	Normalized error *NE*
(-10) 990	-0,094	0,22
(0) 1 000	0,064	0,14
(+10) 1 010	0,019	0,05

6. Conclusion

Results presented in Tables 1 to 6 show that the performance of the laboratories in the calibrations were quite satisfactory for both atmospheric tank provers, especially considering that different calibration methods were used for determination of the reference volumes.

The normalized errors obtained for both tank provers indicates a very satisfactory comparability between the two calibration methods.

Thank you
for your attention!