



South American Interlaboratory Program on Gas Flow Rate

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Abstract: This paper presents an interlaboratory program developed in gas flow and volume measurement area which involved three South American laboratories from Brazil, Argentina and Colombia. The transfer standard meter chosen for the interlaboratory comparison was a G-1000 type gas turbine meter and calibrations were performed in the range from 160 m³/h up to 1600 m³/h, using air at ambient conditions. The results of the comparison program are presented and show that all degree of equivalence (E_{ni}) values of the three laboratories resulted smaller than 1, indicating a very good compatibility among the laboratories. That shows clearly that the reference standards, methodologies and procedures of the three laboratories are comparable in the range of flow rates assessed during the international comparison.

Key words: gas flow measurement, turbine meters, natural gas, interlaboratory comparison.

1. INTRODUCTION

Currently, there is still no national metrology institute in South America with facilities and standards able to provide traceability for high gas flow rate measurements. Under this scenario, in early 2010, three important gas meters calibration laboratories, from Colombia, Argentina and Brazil, decided to develop an interlaboratory comparison program on gas flow measurement using a G-1000 gas turbine meter.

The program followed the directives of the “*The Guidelines*” [1] and “*EAL-P7*” [2] reference documents and the objective was to determine the degree of equivalence among the three laboratories in gas flow measurement.

An interlaboratory comparison is one of the most effective tools to ensure the quality and reliability of the measurements performed by a calibration laboratory. In addition, this program established itself as an important effort towards an integration of the metrological activities in South America, and that is especially important when a growing natural gas market is being built in many countries.

The technical committee of the program, composed of experts of each one of the laboratories, decided to perform

the tests at flow rates ranging from 160 m³/h up to 1600 m³/h, using air at ambient temperature and pressure. These calibration conditions were defined so as to allow all three laboratories to carry out the measurements under their normal operating conditions.

This paper presents the transfer standard used, the main characteristics of the three laboratories, the methodology used, the results obtained and a discussion of the interlaboratory program developed.

2. LABORATORIES INVOLVED IN THE PROGRAM

The laboratories that participated in the interlaboratory comparison program were the Centro de Desarrollo Tecnológico del Gas - Corporación CDT de GAS, located in Piedecuesta / Colombia; the Instituto de Pesquisas Tecnológicas - IPT, located in Sao Paulo / Brazil and the laboratory from Transportadora de Gas del Sur S.A. - TGS, located in Buenos Aires / Argentina.

These laboratories are accredited by their national accreditation bodies in accordance with the ISO/IEC 17025:2005 standard [3], and what means that they operate a quality control system and that the uncertainties associated to the measurements performed in these laboratories are assessed according to the ISO 5168 [4] and GUM [5] guidances.

2.1 CDT de Gas laboratory

The Corporación CDT de GAS laboratory operates a test bench for high gas flow rates (Figure 1), which was designed and built for calibration of gas meters in a operating range from 3 m³/h up to 4 800 m³/h.

Currently, the CDT de Gas laboratory working standards are based on one rotary meter G-100, a turbine meter G-400, and three G-1000 turbine meters operating individually or in parallel to cover the whole measuring range. These meters were calibrated in PTB gas laboratory (Germany) and the installation presents a best measurement capability of 0.16 % ($k = 2$).



Fig. 1. CDT de Gas flow laboratory

The measurements of ambient temperature, pressure and relative humidity are maintained under a metrological assurance program in accordance to the ISO 10012 standard. The CDT de GAS flow laboratory is accredited by the ONAC-Organismo Nacional de Acreditación de Colombia.

2.2 TGS gas flow laboratory

The TGS Calibration and Test Laboratory, is part of the Transportadora de Gas del Sur company, whose main function is to transport natural gas in Argentina.

The laboratory scope for calibration of turbine and rotary meters for natural gas comprises a range from 0.5 m³/h up to 6 500 m³/h.

In this laboratory calibrations are carried out at ambient conditions and the laboratory presents a best measurement capability of 0.28 % ($k = 2$). TGS laboratory covers meters with nominal diameters ranging from DN50 up to DN400.

The flow laboratory of TGS is part of the network of laboratories supervised by the Argentine INTI - Instituto Nacional de Tecnología Industrial. Figure 2 shows a picture of TGS gas flow laboratory.



Fig. 2. TGS gas flow laboratory

2.3 IPT gas flow laboratory

The IPT high gas flow rate laboratory is composed of two calibration benches working with air at atmospheric

conditions: one reaches flows from 0,5 m³/h up to 5100 m³/h and uses as working standards two duo rotary meters and four turbine meters. The other calibration bench is a compact one, for flows from 0,3 m³/h up to 2500 m³/h, using three duo rotary meters.

The traceability of the measurements in IPT high gas flow rate laboratory is assured by a bell prover, calibrated by the dimensional strapping method and verified by a set of sonic nozzles calibrated at PTB and a turbine transfer standard meter also calibrated at PTB. Figure 3 shows a picture of the IPT high gas flow laboratory.



Fig. 3. IPT gas flow laboratory

3. TRANSFER STANDARD METER PACKAGE

3.1 The standard meter

The standard meter chosen for the interlaboratory comparison was a G-1000 turbine meter, as seen in Figure 4.



Fig. 4. The G-1000 turbine meter used as transfer standard

The meter was specified without mechanical index to try to minimize restrictions on mechanical movement, so as to increase the linearity of the meter and with two Namur high

frequency outputs of 3801,1 impulses/m³ for a good resolution. The main characteristics of the turbine meter are presented in Table 1.

Table 1. Main characteristics of the turbine meter

Parameter	Value
Nominal diameter	150 mm
Q_{min}	80 m ³ /h
Q_t	320 m ³ /h
Q_{max}	1 600 m ³ /h
Linearity ($Q_{min} \rightarrow Q_{max}$)	0.5 %
Repeatability ($Q_{min} \rightarrow Q_{max}$)	≤ 0.05 %

The standard was carefully chosen for a good metrological performance, especially in terms of the reproducibility and repeatability. Despite of its good metrological characteristics, special care had to be taken for a proper flow conditioning in the assembling of the meter in each calibration bench.

3.2 Characterization of the standard meter

Before starting the interlaboratory comparison program, an exhaustive series of tests were carried out at CDT de GaAS laboratory to characterize the standard meter.

Stability test: the meter was operated for over 200 hours in order to ensure that it was stable and would not suffer any accommodation effect during the course of the program.

Lubrication: the meter operated totalizing the whole volume expected for the entire program without additional lubrication, and its behavior did not vary, indicating that it would not be necessary to re-lubricate the meter during the course of the program.

Reproducibility: in order to estimate the reproducibility of the meter, three independent calibrations in consecutive days were carried out and the results were compared. Figure 5 shows the test results. A U_{est} value of 0.04 % was estimated for the reproducibility.

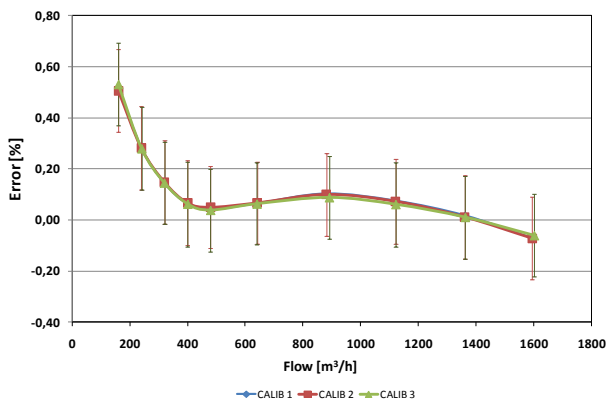


Fig. 5. Reproducibility of the meter in three calibrations

Flow conditioner: tests were performed in order to verify if the use of flow conditioners could indeed affect the meter. Results showed that the use of a flow conditioner was

recommended and it was agreed that each laboratory was allowed to use its own flow conditioner.

3.3 Meter package

For a safe transportation, a polyurethane box package was arranged to accommodate the meter inside it. The meter was carefully tied into the box. Figure 6 shows pictures of the box and of the turbine inside it.

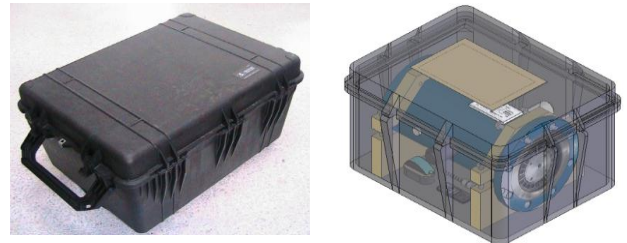


Fig. 6. Pictures of box package

4. COMPARISON METHODOLOGY

The interlaboratory comparison was agreed to occur in a calibration interval ranging from 160 m³/h up to 1600 m³/h, with air at ambient conditions of pressure and temperature.

Each laboratory took at least three runs in each set-point flow rate as indicated in Table 2, using its own calibration procedure.

Table 2. Comparison flow set-points

Set-point	Flow rate (m ³ /h)	Set-point	Flow rate (m ³ /h)
1	160	6	640
2	240	7	880
3	320	8	1 120
4	400	9	1 360
5	480	10	1 600

The set-points were chosen so as to match with the set-points of a previous PTB calibration of the standard meter occurred in 2008, in order to enable a comparison of the results with the previous calibration for reference.

4.1. Standard meter installation

Each laboratory used its own straight pipe run to assembly the meter in the calibration bench. Figure 7 shows a typical installation used to calibrate the meter.

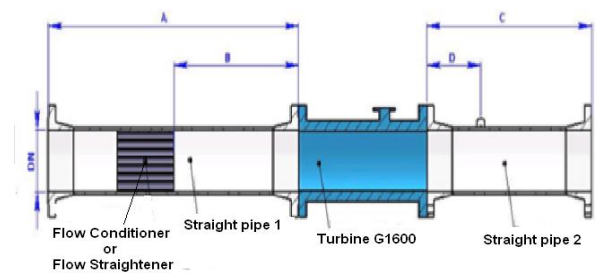


Fig. 7. Straight pipe run for meter installation

Table 3 presents the main dimensional parameters used by each laboratory to assemble the turbine meter in its own calibration bench.

Table 3. Meter installation dimensional parameters

Laboratory	A (mm)	Flow conditioner/straightener	B (mm)	C (mm)	D (mm)	PRT diameter (mm)
TGS	1 524	19 tubes	1 200	762	152	6,35
IPT	1 580	Mitsubishi	830	300	300	3,00
CDT	1 676	Mitsubishi	899	301	301	4,76

4.2. Measurand

The measurand defined for the comparison was the measurement error [7] in percentage, obtained in the calibration of the turbine meter, as defined by Equation (1):

$$E (\%) = \frac{V_{G1000} - V_{Lab}}{V_{Lab}} \cdot 100 \quad (1)$$

where:

$E (\%)$: measurement error of the turbine meter, in percentage
 V_{G1000} : volume indicated by the turbine meter
 V_{Lab} : reference volume measured by the laboratory

4.3. Comparison sequence

The three laboratories decided to use the star type directives of “EAL-P7” [1] for the interlaboratory program, resulting in the following sequence: CDT de GAS – TGS – CDT de GAS – IPT – CDT de GAS.

4.4. Uncertainty

Each laboratory was responsible for assessing and declaring the uncertainties associated to the measurement results of the calibration, considering the GUM [5] and ISO 5168 [4] directives.

4.5. Reference value

The *comparison reference value (CRV)* was calculated and validated using the methodology proposed by Cox [6].

According to this methodology, the *CRV* was taken as the mean of the errors informed by each laboratory, for each flow set-point, weighted by the inverses of the squares of the associated standard uncertainties, as presented in Equation (2).

$$CRV = \frac{\sum \left(\frac{x_i}{u^2(x_i)} \right)}{\sum \left(\frac{1}{u^2(x_i)} \right)} \quad (2)$$

where:

x_i : measurement error (E) of each laboratory (i) for the same set-point;
 $u(x_i)$: standard uncertainty declared for each laboratory (i) for the same set-point.

The standard uncertainty of the reference values (u_{CRV}) was calculated combining the uncertainties (u_i) of each laboratory (i) as shown in the Equation (3).

$$\frac{1}{(u_{CRV})^2} = \frac{1}{(u_{CDT})^2} + \frac{1}{(u_{TGS})^2} + \frac{1}{(u_{IPT})^2} \quad (3)$$

4.6. Reference values validation

The validation of the *CRV* and u_{CRV} values was done as proposed by Cox [6] using the chi-squared value (χ^2_{obs}) as follows:

$$\chi^2_{obs} = \sum \frac{(x_i - CVR)^2}{u^2(x_i)} \quad (4)$$

The degrees of freedom (ν) were assigned as $(N-1)$, where N is the number of laboratories.

The consistence check was done using the Equation (5):

$$\Pr \{ \chi^2(\nu) > \chi^2_{obs} \} < 0.05 \quad (5)$$

where:

\Pr : is the “probability of”

If the values satisfy the condition, *CRV* and u_{CRV} can be accepted as the reference value.

4.7. Difference

For each laboratory, the difference (d_i) and the standard uncertainty ($u(d_i)$) of d_i can be calculated as:

$$d_i = x_i - CRV \quad (6)$$

And

$$u^2(d_i) = u^2(x_i) - u^2_{CRV} \quad (7)$$

4.8. Degree of Equivalence

Another parameter used to analyze the deviation of each laboratory from the reference value was the degree of equivalence (E_{ni}) calculated according to the Equation (8).

$$E_{ni} = \left| \frac{d_i}{2 \cdot u(d_i)} \right| = \left| \frac{d_i}{U(d_i)} \right| \quad (8)$$

Reference [8] defines the following analysis in terms of the absolute value of E_{ni} :

- $E_{ni} \leq 1$: the results of the laboratory are acceptable (passed);
- $E_{ni} > 1,2$: the results of the laboratory is not acceptable (failed), such estimation signals on serious problems of

the laboratory, which must be analyzed and removed for proper functioning of the laboratory;

- $1 < E_{ni} \leq 1,2$: values of E_{ni} in this range are defined as warning level, where action to check is recommended to the laboratory.

5. RESULTS

The results were first analyzed accordingly to the methodology proposed by Cox [6] and described in item 4.6. This validation analysis showed that the values of CRV and U_{CRV} could be accepted and, therefore, were validated.

Table 3 shows the results obtained in the program for each laboratory.

Table 3. Results obtained in the program

Flow (m ³ /h)	CDT DE GAS				TGS				IPT			
	x_i (%)	$U(x_i)$ (%)	di (%)	En_i (-)	x_i (%)	$U(x_i)$ (%)	di (%)	En_i (-)	x_i (%)	$U(x_i)$ (%)	di (%)	En_i (-)
160	-0,10	0,30	-0,01	0,05	-0,14	0,28	-0,05	0,23	-0,04	0,24	0,05	0,26
240	-0,16	0,22	0,01	0,08	-0,33	0,28	-0,15	0,63	-0,09	0,22	0,08	0,48
320	-0,18	0,22	0,08	0,49	-0,47	0,28	-0,21	0,85	-0,22	0,22	0,04	0,51
400	-0,17	0,22	0,11	0,60	-0,44	0,28	-0,16	0,67	-0,28	0,22	0,00	0,02
480	-0,15	0,23	0,10	0,54	-0,36	0,28	-0,11	0,46	-0,27	0,22	-0,02	0,25
640	-0,08	0,22	0,06	0,34	-0,20	0,28	-0,06	0,25	-0,16	0,22	-0,02	0,24
880	-0,02	0,21	0,07	0,46	-0,19	0,28	-0,09	0,38	-0,12	0,22	-0,02	0,27
1120	-0,02	0,21	0,05	0,35	-0,20	0,28	-0,12	0,50	-0,05	0,30	0,03	0,23
1360	-0,06	0,23	0,10	0,58	-0,31	0,28	-0,15	0,64	-0,16	0,30	0,00	0,02
1600	-0,08	0,26	0,17	0,82	-0,42	0,28	-0,18	0,78	-0,26	0,30	-0,02	0,15

The final results of the program can be seen in Figure 8, that presents the error and the uncertainty obtained for each laboratory and the CRV as a function of the flow rate.

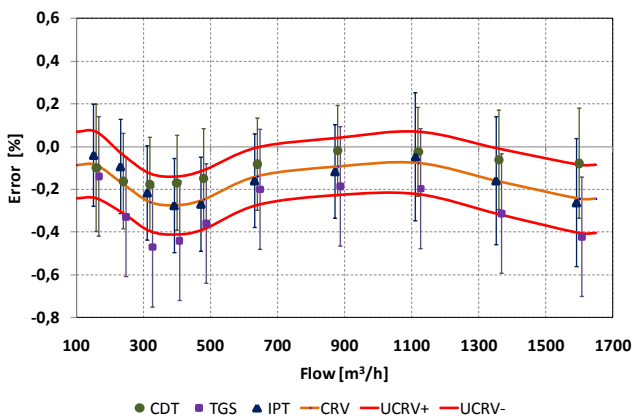


Fig. 8. Results of the measurand

where:

$Error$ (%) : measurement error of the turbine meter and the declared uncertainty by each laboratory at each nominal flow rate.

Figure 9 presents the degree of equivalence (E_{ni}) for each laboratory as function of the flow rate.

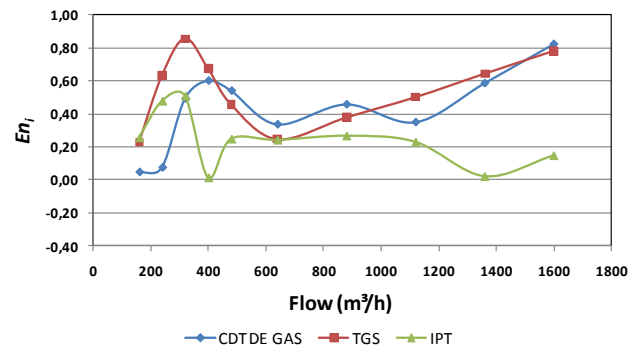


Fig. 9. Results of degree of equivalence

6. DIFFICULTIES OF THE PROGRAM

Though the special care taken in the organization of the interlaboratory comparison, in the careful specification of the transfer standard, in its exhaustive characterization prior to the tests and in its special package for transportation, the program experienced some unexpected difficulties.

The results presented on item 5 were obtained only after a second comparison round that had to be done after the IPT calibration.

After the meter initial calibration in CDT de GAS, the meter was sent to TGS in Argentina. In this transportation the package was dropped at the airport and suffered some damage generating doubts about the meter condition. At TGS, after the meter calibration, a new and better package was made and the meter returned to Colombia. The second calibration in CDT de Gas was carried out and the meter did not show any significant difference in its performance, meaning that despite of the problem in the transportation in Argentina, the meter did not suffer any damage and it was not necessary to interrupt the process. Also, the comparison results between TGS and CDT de GAS were considered to be in a very good agreement.

The meter was then send to Brazil and when leaving Colombia had some clearing problems in the Colombian customs. Arriving in Brazil, the meter also had clearing problems and remained trapped for more than 2 months in the customs. When finally the meter arrived at IPT, despite of the delay, there was no apparent indication of any damage in the package neither in the meter itself. Then, IPT carried out its calibration.

When the results of the three laboratories were compared, they showed some significant differences between the calibrations especially at low flows.

Figure 10 shows the differences obtained in the first comparison round between the three laboratories.

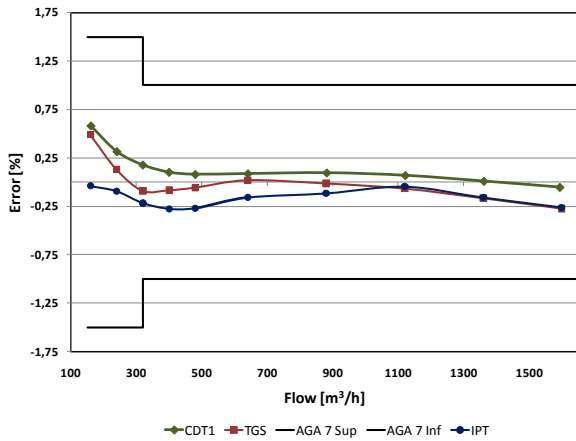


Fig. 10. Results of the first comparison

After the meter was returned to CDT de GAS, a third calibration at this laboratory was carried out and the results showed a very close agreement to the IPT calibration data.

This fact raised a suspicion that the meter could have suffered some mechanical interference in the customs during transportation from Colombia to Brazil that affected the meter performance.

To check this doubt, the meter was again sent to TGS and a new calibration was carried out. The TGS results this time were very close to IPT and CDT de Gas results indicating that, indeed, a transportation problem happened. This last calibration results are the ones presented in item 5 of this paper.

7. CONCLUSIONS

All the E_{ni} values of the three laboratories resulted smaller than 1, and considering the thirty values presented, only ten are higher than 0.5. Therefore, an objective evaluation of the results of the interlaboratory program for gas flow rate and volume calibration showed that the three laboratories presented a very good consistency among them. This indicates that the reference standards, methodologies and procedures of the three laboratories were comparable in the range of flow rates from 160 m³/h up to 1600 m³/h assessed during the international comparison.

Especially due to the logistics problems related in item 6, for the next interlaboratory programs it is strongly recommended to use more than one transfer standard meter and to take more care about the meter package and the customs problems.

ACKNOWLEDGEMENTS

The authors are grateful to the Centro de Desarrollo Tecnológico del GAS - Corporación CDT de GAS for organizing the interlaboratory program and supplying the transfer standard, and also to the Instituto de Pesquisas Tecnológicas-IPT and Transportadora de Gas del Sur S.A.-TGS companies for financially supporting the calibrations and transportation costs.

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