Science is but a perversion of itself unless it has as its ultimate goal the betterment of humanity. ***Nikola Tesla***

Scientific activity is addressed to satisfy curiosity and solve hesitations about how natural laws are arranged and which ones they are.

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Development a MÓVIL LABORATORY for Metrological Assurance of quality and quantity in Natural Gas Custody Transfer In Colombia

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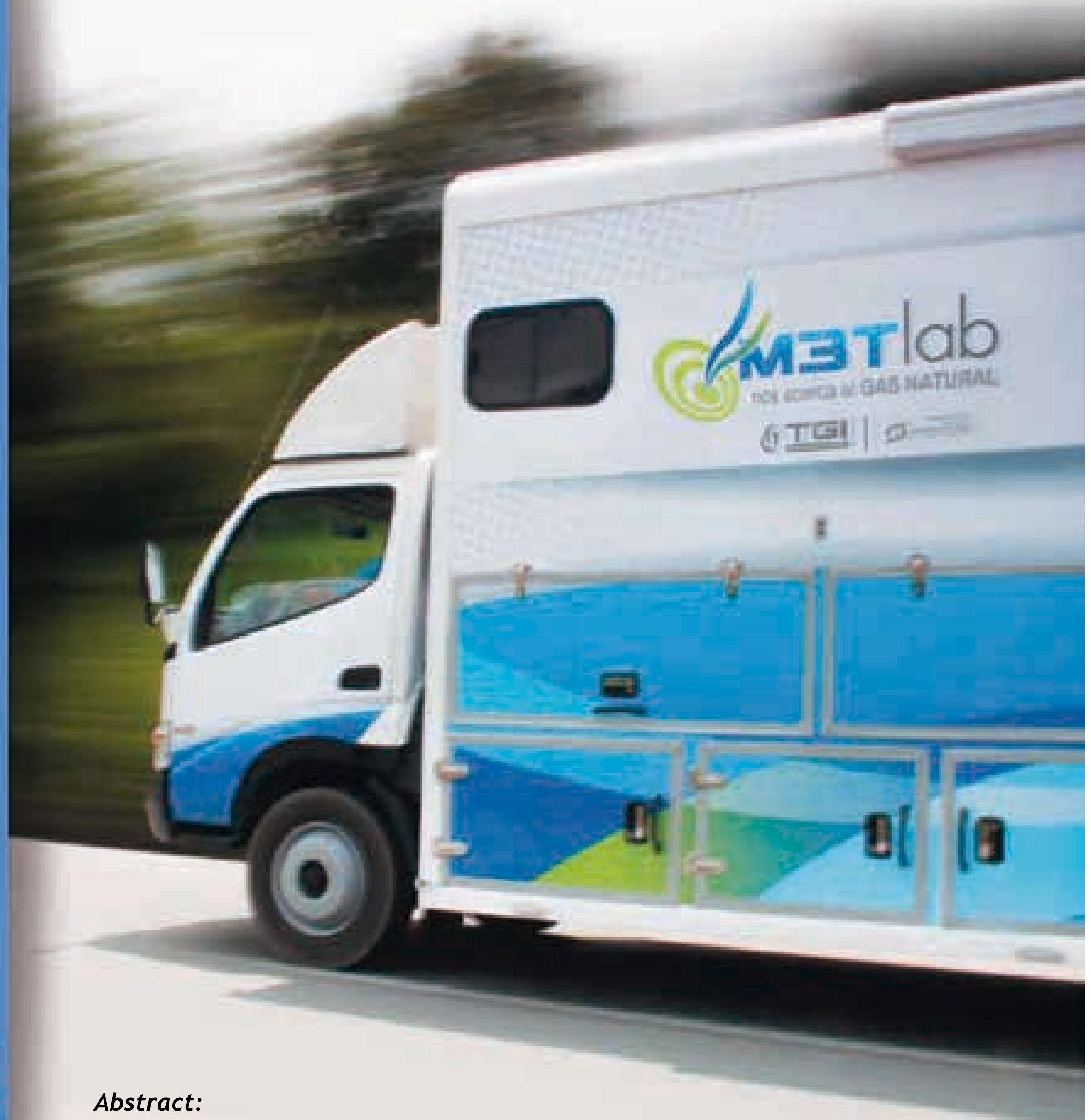


Abstract:

As an alternative to provide traceability to measurements of Quality and Quantity of Natural Gas on-site, was developed by the Technological Development Center of Gas and the International Gas Transportation Company, with the support of COLCIENCIAS, a New Mobile Metrology laboratory, that integrates the facilities to operate as a permanent metrological laboratory and also with Calibration and Measurement Capabilities (CMC) according to the requirements of the natural gas measurement process.

1. INTRODUCCIÓN

The relevance of providing traceability to gas quality and quantity in field increases every day. However, this task is expensive, generates risks related to equipment transport, demands adequate logistics and the required time to fulfill the measurement assurance process (calibration, confirmation and correction) may be long, causing disagree among agents involved in the natural gas custody transfer process.

As a feasible alternative to provide traceability to the measurements of gas quality and quantity in field, International Gas Transmission Company (TGI S.A. ESP) and the Gas Technological Development Center (CDT de GAS), supported by COLCIENCIAS, planned and carried out the design and commissioning of a mobile laboratory integrating the facilities to operate as a stationary metrology laboratory and CMC conform to the requirements of the natural gas measurement processes.

The concept of mobile laboratory came up from the necessity to keep strengthening and improving the transparency and equity in natural gas custody transfer operations, by means of the metrological assurance of the small MS of the TGI S.A. ESP transmission system which quantifies 15% of the gas transmitted but it represents the highest amount of MS (more than 250). In general, these systems belong to small towns and industries, metrologically highly vulnerable since, due to the low volumes involved, does not have a metrological assurance strategy for guaranteeing 100% of NG quantified, given that most of the efforts are focused on MS dealing with the highest volumes, according to Pareto principle.

However, TGI S.A. ESP, with the target to become a world class company and to guarantee efficiency and equity in the NG transmission service, generating a high added value to its interest groups, independent from its financial dimension, has not limited its efforts to comply only what is necessary according to the regulation in terms of assuring its measurements and thus planned the development of a mobile laboratory, autonomous and able to thoroughly execute all the processes to assure the quality and quantity of NG transmitted and measured in type-B and type-C MS according to the OIML R140 guidelines [1]

As a result, a vehicle was set up as a mobile laboratory, which stores, transport and operates the standards and measurement instruments required to evaluate the composition of C10+, HCDP and natural gas humidity, and calibrate the instruments measuring the quantities involved in the custody transfer process, such as: gas volume, pressure, temperature, frequency and electrical quantities associated, under Quality Management System ISO/IEC 17025. Additionally, it is possible to perform electromechanical maintenance tasks to the measurement system, guaranteeing the NG quality and quantity measured in the MS.

This metrology mobile laboratory was denominated M3Tlab due to its fundamental characteristics: Metrology, Mobility, Maintenance and Traceability (MMMT). This concept game leads us to a simple equality: MMM=M3, and thus we obtain M3T (or MET for Metrology) and lab for laboratory. Coincidentally when reading M3 cubic meter is noticed (m^3), a key quantity when measuring gas volume.

2. ABBREVIATIONS

CMC	Calibration and Measurement Capabilities
COE	Cab over engine
CREG	Acronym for the Colombian Energy and Gas Regulatory Body
EOS	Equation of State
FAT	Factory acceptance test
G	Gravitational acceleration
HCDP	Hydrocarbon Dew Point
ISO	International Organization for Standardization
MPE	Maximum permissible error
MS	Measuring System
NG	Natural Gas
RGM	Reference Gas Mixture
RUT	Acronym for the document on natural gas regulatory measurement policies in Colombia [1]
SAT	Site acceptance test
Ur	Uncertainty required [2, p. 11.1.2]
VCML	Vehicle Conditioned as Mobile Laboratory
%RSD	Relative standard deviation

3. MEASURING INTERVALS

In order to provide the CMC required for the metrological assurance of the MS, the M3Tlab laboratory was developed considering the functional specifications of the MS and its target instrumentation, as well as the requirements given in the Recommendation OIML R 140 [3] for systems with an accuracy class type B. This work implied the development of several states of the art ([4][5][6]), which allowed to study, compare and select, with supporting information, the technological alternatives to reach the expected CMC. The measuring intervals provided for M3Tlab are described below.

3.1. NATURAL GAS VOLUME

The technical specifications of the population of gas meters to calibrate with M3Tlab were taken into account for the development of the volumetric standard (Table 1). Also were considered the metrological and functional requirements necessary to guarantee the execution of calibrations with a CMC value close to 0.3% (k=2) in the determination of the measurement error.

Meter type	Measuring Interval	Meter Specifications	MPE [1][2]
Rotary piston and turbine	2 m³/h a 650 m³/h	**DN:** 50 mm a 100 mm **Connections:** PN 20 a PN **Outputs:** Index, LF and HF	1%

***Table 1**. Technical specifications of the gas meters to be calibrated with M3Tlab*

3.2. NATURAL GAS QUALITY

Considering the typical compositions of the Colombian natural gas, the need of a semi-extended NG analysis was projected, according to the measuring intervals given in Figure 1. By this means and using gas mixture laws, together with EOS, several properties of interest for the NG industry can be calculated, as for example: calorific value, hydrocarbon dew point temperature, density, compressibility factor, speed of sound, viscosity, and others. These properties and its specification limits are shown in Table 2.

To reduce the uncertainty associated to the NG sampling, a system with a probe, specially designed to allow its easy installation in the pipeline, was specified and configured. By this way it is possible to perform spot sampling and assuring the acquisition of representative samples from the natural gas flow.

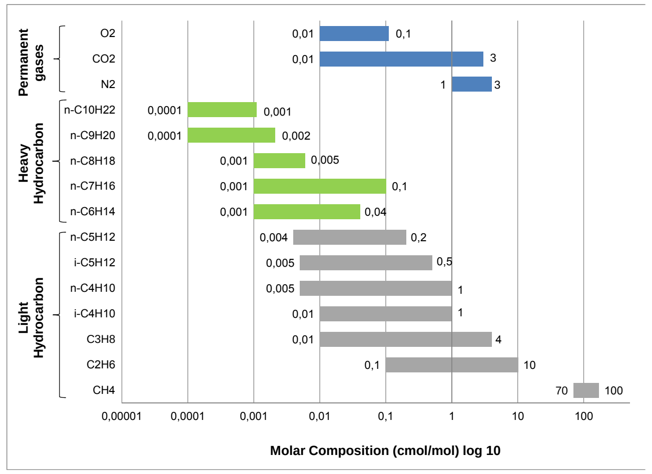


***Figura 1**. Components and ranges of concentration for natural gas analysis*

Property	Measurement method	Measuring interval
NG composition	Chromatography C10	Extended chromatography up to C10+. (Figure 1)
Calorific value	Chromatography C10 + mixture laws	33.53 MJ/m³ a 44.71 MJ/m³
Hydrocarbon dew point temperature	Chromatography C10 + EOS	-34 °C a 15.56 °C
Concentration of water vapor	Absorption in aluminum oxide sensor	10 mg/m³ a 590 mg/m³

***Table 2**. Key measurands and specification limits in the gas quality module*

3.3. ASSOCIATED MEASURANDS

Pressure, temperature and other measurands are obtained by electronic instruments, requiring metrological assurance in quantities as for example: electric resistance, current, voltage and frequency. Table 3 shows the measuring intervals for this associated measurands.

Measurand	Measuring interval	MPE [5]
Gauge pressure	10.34 kPa – 206.8 kPa	0.2 kPa
	103.4 kPa – 2 068 kPa	2 kPa
	517 kPa – 10 342 kPa	10.3 kPa
Temperature	-10°C a 150 °C	0.5 °C
DC Electric potential	-15 V a 15 V	5 mV
DC Electric current	0.1 mA a 22 mA	8 µA
DC Resistance	10 Ohm a 200 Ohm	0.01 Ohm
Frequency	1 Hz a 10 000 Hz	0.1 Hz

***Table 3**. Measuring intervals and MPE for associated measurands*

3.4. MAINTENANCE CAPABILITIES OF M3Tlab

As a part of a complementary unit, the capacity to do basic maintenances to the MS and its associated instruments was considered to be included as an integral section of M3Tlab. In this case, the requirements were the following:

- Electrical ground testing
- Insulation testing
- Electrical signals analysis
- Disassembly, load lifting and mounting of MS components
- Basic electromechanical maintenance of instruments and components

3.5. CHALLENGES

The measuring intervals described previously represent a broad assortment of operational and metrological capacities, including physical and analytical quantities. These capacities have been hugely developed, implemented and documented for stationary laboratories.

However, integrating all the measurands cited before, inside a mobile laboratory, is a problem without a notable background because it has not been discussed or documented in previously works.

This condition led to do analysis and studies oriented to the design and adaptation of a vehicle to enable its use as a mobile laboratory, able to safely store and transport the measurement equipment, minimizing a probable affectation on the metrological performance, as a consequence of impacts and vibrations who take place during the displacement of the vehicle on the Colombian roads.

Moreover, there was the need of reduce the size of the mobile laboratory without generate an impact over its operational capacities. To accomplish this, it was necessary to design a suitable facilities planning and layout, oriented to the process of metrological assurance of the MS in the field. This goal was reached through the adaptation a vehicle, as small as possible, providing good mobility characteristics and allowing an easy access to the metering stations.

The facilities necessary to generate (in the field), a set of conditions, similar to those found in a stationary laboratory were taken into account during the design and adjustments of the vehicle. Primarily to ensure reproducibility of the calibration and test methods. For this reason the following aspects were considered as mandatory:

- Possibility of connect the vehicle to a conventional electrical power supply (electric network) if it was available.
- Autonomous generation of electrical power, enough to supply energy to the entire set of equipment required for a properly and complete laboratory operation.
- Thermic isolation and fluid-dynamic design, oriented to maintain the stability in the temperature, regardless of the place where it operates.
- Facilities for the handling and provision of specialty gases and RGM used in gas quality tests.
- Anti-vibration mounts for equipment sensitive to vibrations taking place during transportation.
- Easiness of access and mobility inside the vehicle (ladders, load platforms, etc.)
- Engine power must be enough to allow the transportation of all crew and equipment.
- Ergonomic and safe spaces for the technical staff during its working sessions.

4. RESULTS ACHIEVED

Once established the requirements matrix, from the analysis of the measuring intervals and the challenges, it was possible to start a multidisciplinary work, involving engineers and metrology experts in multiple disciplines. As a result the design of the laboratory was achieved.

4.1. VEHICLE CONDITIONED AS A MOBILE LABORATORY

4.1.1. Suspension and anti-vibration systems

The conditioning of the vehicle as mobile laboratory (VCML) was one of the most complex results to reach in the project. M3Tlab was integrated on a small truck HINO 300 Dutro Max manufactured by Toyota [7], provided with a COE type cabin, conventional leaf springs in the rear suspension (semi-elliptic) and shock absorbers with double action.

This configuration can be easily obtained in the Colombian market and is commonly used for load transportation, mainly because its stiffness, long term life and low maintenance costs. However, this type of suspension transfers low frequency vibrations or impacts to the load [8], [9], [10].

These undesirable effects do grow with the vehicle speed, suspension stiffness and road quality [11]. For these reasons a special suspension system was designed and located between the truck chassis and the laboratory container or truckvan. This system reduces the magnitude of impacts with no risks on the stability of the mobile laboratory during its displacement.

The simple and effective solution was to install conical mounts longitudinally distributed (Figure 2), according to the expected mass distribution. The result obtained was represented by a reduction of the acceleration vector (three-axis) related with the impact that take place during transit.

In order to validate the effectiveness of the suspension, several routes with different terrain properties (wavy, potholes, pavement in bad condition or unpaved roads) were programmed and realized. In this test the impacts on the chassis (conventional suspension) and the truckvan (conditioned suspension) were recorded by means of three-axis accelerometers, configured with trigger at 1.5 G[1] and a sampling frequency of 50 kHz. By this way, the capacity of the suspension set was successfully confirmed with a reduction rate of 80% in the impacts magnitude (Figure 3 y Figure 4).

Although the conditioned suspension (second vibration damping level) allowed a reduction in the impacts level up 4 G, a third damping level was installed in order to reduce the impacts at a superior grade. This action had effects both on the equipment permanently mounted (fixed to the VCML), such as the chromatograph, electric generator, compressors, volumetric standard, etc. as well as the stored equipment because the workbenches and lockers have anti-vibration mounts in its fixation to the VCML.

[1] *Gravitational acceleration. For the described experiments it corresponds to the local gravitational acceleration in the city of Piedecuesta (Colombia) 9.7778 m/s² [12]*

***Figure 2**. Anti-vibration systems mounted on the VCLM for impact mitigation*

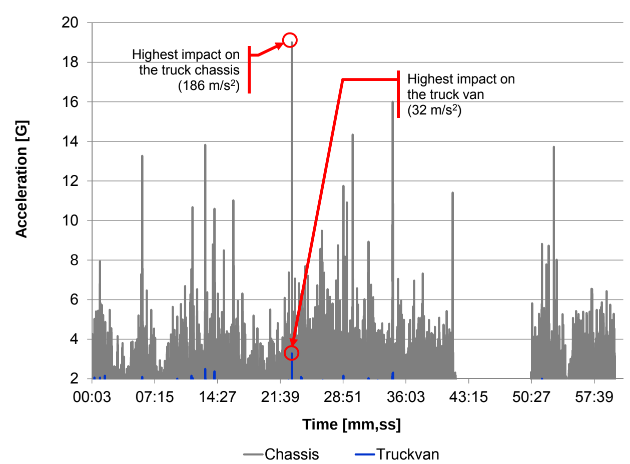


***Figure 3**. Impacts recorded during SAT tests (on the road)*

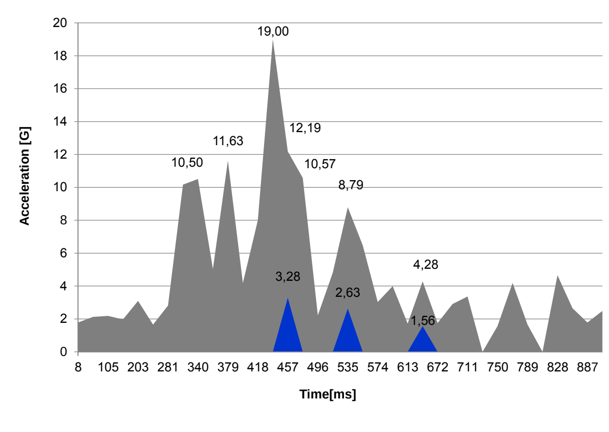


***Figure 4**. Comparison of impact mitigation*

4.1.2. Facilities planning and layout of operational modules

After some design iterations and the selection of the technologies and equipment to mount on the vehicle, a compact, flexible and personalized plant layout was obtained, responding to the requirements given by the calibration, test and maintenance processes. Figure 5 shows in dotted lines the laboratory areas or modules.

Modules A, B, C and D are located inside the truckvan, while the E module has its access from the outside (laterally).

4.1.3. Service facilities and results

The mobile laboratory capacity to operate in the field with no restrictions and a set of conditions and facilities, similar to those found in a stationary laboratory, it was necessary to integrate in the VCML of all the equipment listed in Table 4.

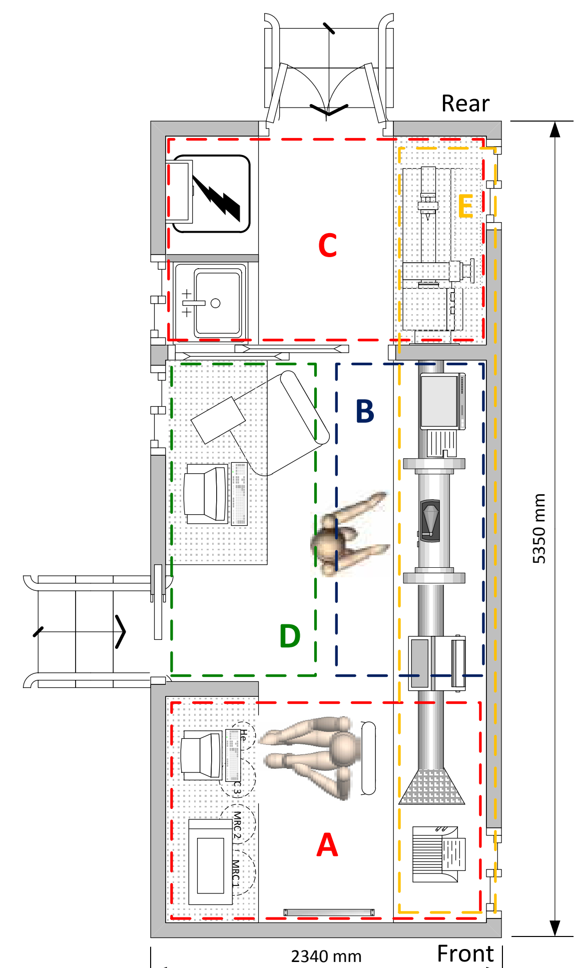


***Figure 5**. Facilities planning and layout. A-Gas quality. B- Associated measurands. C-Maintenance. D-Multi-purpose module. E- Gas volume*

4.2. PERFORMANCE AND METROLOGICAL STABILITY

The operative and metrological scopes related in section 3 were totally implemented during the integration stage. Subsequently, FAT and SAT tests were carried out, both to single modules as well as the whole assembly.

These tests were the key to evaluate the capacities of the mobile laboratory and were conducted as a part of the strategy for monitoring its performance along the time (see Table 5) and under different environmental conditions.

Equipment	Specifications	Performance
Electric generator	Inverter technology with a maximum power of 6.5 kW and output at 120/240 VAC (60 Hz)	Sinusoidal waveform at 60 Hz, proportional supply to electric load and an autonomy up to 10 hours
Air conditioning	Vehicle mounted type, cooling power of 2.63 kW and R-410A refrigerant	Stability range of ±1.5°C per hour at temperatures 5°C below the Tamb
Mid-pressure air compressed system	Single stage compressor with 5 µm filter	6.5 m³/h @ 0.82 Mpa
High-pressure air compressed system	Double stage compressor with 0.5 µm filter and membrane dryer to obtain air with a dew point of -15°C at Patm	0.6 dm³/h @ 20.7 Mpa

***Table 4**. Additional equipment integrated in the VCLM*

Magnitud	Estrategia para Monitoreo de Desempeño	Desempeño obtenido en pruebas FAT y SAT
Volumen de Gas	Verificación periódica, mediante calibración de un medidor rotativo de transferencia	Ver Numeral 4.2.1
Composición de Gas C10+	Ajuste periódico multinivel, de factores de respuesta, utilizando 3 MRG. Monitoreo del tiempo de retención, ruido y deriva en la respuesta del microcromatógrafo	Ver Numeral 4.2.2
Contenido de Vapor de Agua	Comparación periódica con sensor de referencia	En proceso de evaluación de desempeño
Presión	Comparación entre manómetros electrónicos sobre su intervalo de operación común	Estabilidad en la reproducción
Temperatura	Comparación periódica con sensor de temperatura tipo RTD y reproducción del punto de hielo	Estabilidad en la reproducción
Magnitudes Eléctricas	Calibración periódica con medidor-generador multifunción	En proceso de evaluación de desempeño

***Table 5**. Strategy for monitoring metrological performance*

In the following sections are describing the main strategies shown in Table 6, planned for volume and quality modules.

4.2.1. Performance tests for the Gas Volume Module

The volume standard was integrated and its standard meters and measurement instruments were characterized and calibrated in the CDT de GAS laboratory, accredited by ONAC (the national accreditation body), according to the ISO/IEC 17025 guidelines [13]. In the case of FAT and SAT tests, a double-piston rotary meter was used, whose flow rate range from 1.6 m^3/h to 250 m^3/h, specified and acquired as the reference meter for the periodical verifications of the M3Tlab volume standard. This meter was previously characterized in the laboratory in order to confirm its metrological robustness and obtain the results of an initial calibration (see Cod LAB in Table 6), performed under laboratory controlled conditions. The initial error values were taken as reference values to compare against the calibration curves obtained later in the laboratory and in field, under ambient conditions described in Table 6.

In order to evaluate the volume standard stability were taken into account COX [14] criteria, applicable to comparisons, obtaining standard errors less than 0.35 which confirms the M3Tlab standard volume reproducibility, under several operating conditions in laboratory and in field.

As a reference graph of the performance obtained with the volume standard is presented in Figure 6, the deviation d_i (y axis) of errors (E_i) in the multiple calibrations respect to errors in the initial calibration (d_i=0 y axis).

Cod	Ciudad	Fecha* MM-DD	Altitud [msnm]	Patm [kPa]	Tamb [°C]	HR [%]
LAB	Piedecuesta	02-26	1 000	90.06	921.4	55.1
LAB1	Piedecuesta	02-28	1 000	90.08	21.3	50.4
LAB2	Piedecuesta	03-01	1 000	90.47	20.9	52.1
PDT	Piedecuesta	05-05	1 000	90.52	25.5	63.5
BCB	Barrancabermeja	04-24	100	100.36	28.5	77.5
TNJ	Tunja	05-07	2 950	70.62	13.2	88.4

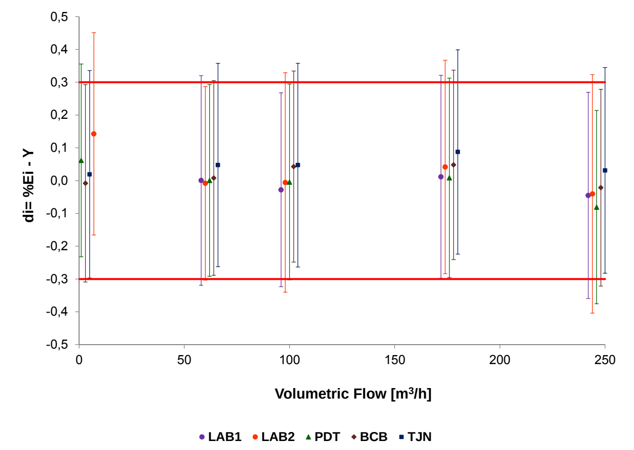
* Año: 2013

Table 6. Testing conditions for the volumetric standard[2]

4.2.2. Performance tests for the Gas Quality Module

The main gas quality test installed in M3Tlab agrees with the determination of the GN C10+ composition. This test is carried out using a microchromatograph which separates and detects

[2] *To help the viewing of the results, these have been slightly displaced around the real flow rates tested.*



Horizontal red lines correspond to uncertainty of the initial errors, taken as reference values.

Figure 6. Instrumental drift evaluated on the reference meter

GN compounds in 3 minutes, using Helium as carrier gas. This instrument has a detection limit of 1 ppm, and a 1 μL minimum injection volume compound by four independent chromatographic modules having the following configuration:

- Column Hayesep A, 0,4m, Heated Injector, Backflush.
- Column CP-Sil 5 CB, 4m, Heated Injector, Backflush.
- Column CP-Sil 5 CB, 8 m, Heated Injector.
- Column MS5A PLOT, 20m, Heated Injector.

When evaluating the microchromatograph performance, 3 RGM were used, prepared with the gravimetric method and concentrations lying within the foresaw interval (Figure 1), mass uncertainty ≤ 1% and HCDP ≤ 0° C. The tests consisted in the evaluation of repeatability and reproducibility of the microchromatograph response area under the conditions described in Table 7.

Id.	Location	Altitude [mamsl]	Patm [kPa]	Tamb [°C]	HR [%]
PDT	Piedecuesta	1 000	90.52	23.0	60.0
BCB	Barrancabermeja	100	100.36	25.0	68.5

Table 7. Testing conditions for the Microchromatrograph

The results indicated that the repeatability and reproducibility are characteristics of each group of compounds (permanent gases, Light Hydrocarbon and Heavy Hydrocarbon), and the concentration range of the compound of interest. Therefore, it was established a matrix for monitoring the performance of the GC in terms of repeatability (Table 8) and Reproducibility (Table 9).

Concentration Ranges	100 – 10 [cmol/mol]	10 – 1 [cmol/mol]	1 – 0,01 [cmol/mol]	0,01 – 0,0001 [cmol/mol]
Permanent gases	-	< 0,8	< 6	< 10
Heavy Hydrocarbon	-	< 0,5	< 2	< 5
Light Hydrocarbon	< 0,2	< 0,2	< 1	< 1,75
Maximum %RSD obtained at the evaluation of 3 RGM (between the concentration intervals of interest), based on the average of three consecutive injections.				

Table 8. Repeatability [%RSD] in the response areas of the micro-chromatograph

Concentration Ranges	100 – 10 [cmol/mol]	10 – 1 [cmol/mol]	1 – 0,01 [cmol/mol]	0,01 – 0,0001 [cmol/mol]
Permanent gases	-	< 2,5	N/D	< 20
Heavy Hydrocarbon	-	N/D	N/D	< 7,5
Light Hydrocarbon	< 0,35	< 0,5	< 2,5	N/D
Maximum %RSD obtained at the evaluation of 3 RGM (between the concentration intervals of interest), based on the average of three consecutive injections, carried on three consecutive days, turning off and on the equipment everyday				

Table 9. Reproducibility [%RSD] in the response areas of the micro-chromatograph

5. PROJECTION

Even though the main objective in M3Tlab development and application lies in the NG measurement systems metrological assurance to small towns and companies with metrological vulnerability, it is expected to take good profit of its characteristics to perform studies about the calibration performance and tests in-situ, technical staff training (metrologists) and dissemination of the benefits of metrology in industry, given the ease of transportation, location and operation under wide ambient conditions.

In short term a pre-operative stage will be carried out which is expected to continue the evaluation and improvement of the M3Tlab metrological performance parameters and experience to start interlaboratory comparison processes will be obtained in order to support declared CMC and later ask for the accreditation according to ISO/IEC 17025 guidelines [13]

6. CONCLUSIONS

- M3Tlab, including developed instruments or subsequently acquired and integrated to the system providing it with the capacity to operate in-situ with similar characteristics to those stationary metrology laboratories, was tested and proved to perform as predicted by means of FAT and SAT tests
- The efficiency of the suspension system and the anti-vibration systems were proven which were installed to reduce 1) the impact when moving the VCML and 2) vibrations caused by the facilities (electric generator, air conditioned and compressors)
- The results about the metrological performance of the procedures, and calibration and measurement instrument integrated to M3Tlab, evaluated during FAT and SAT, confirmed the accomplishment of the metrological requisites predicted as mobile laboratory range.
- Performance tests described in the present paper correspond to the most representatives, initially executed to validate the development obtained. However, several metrological and functional tests were carried out issuing successful results, but due to its extension they will be described in detail and individually in future opportunities.

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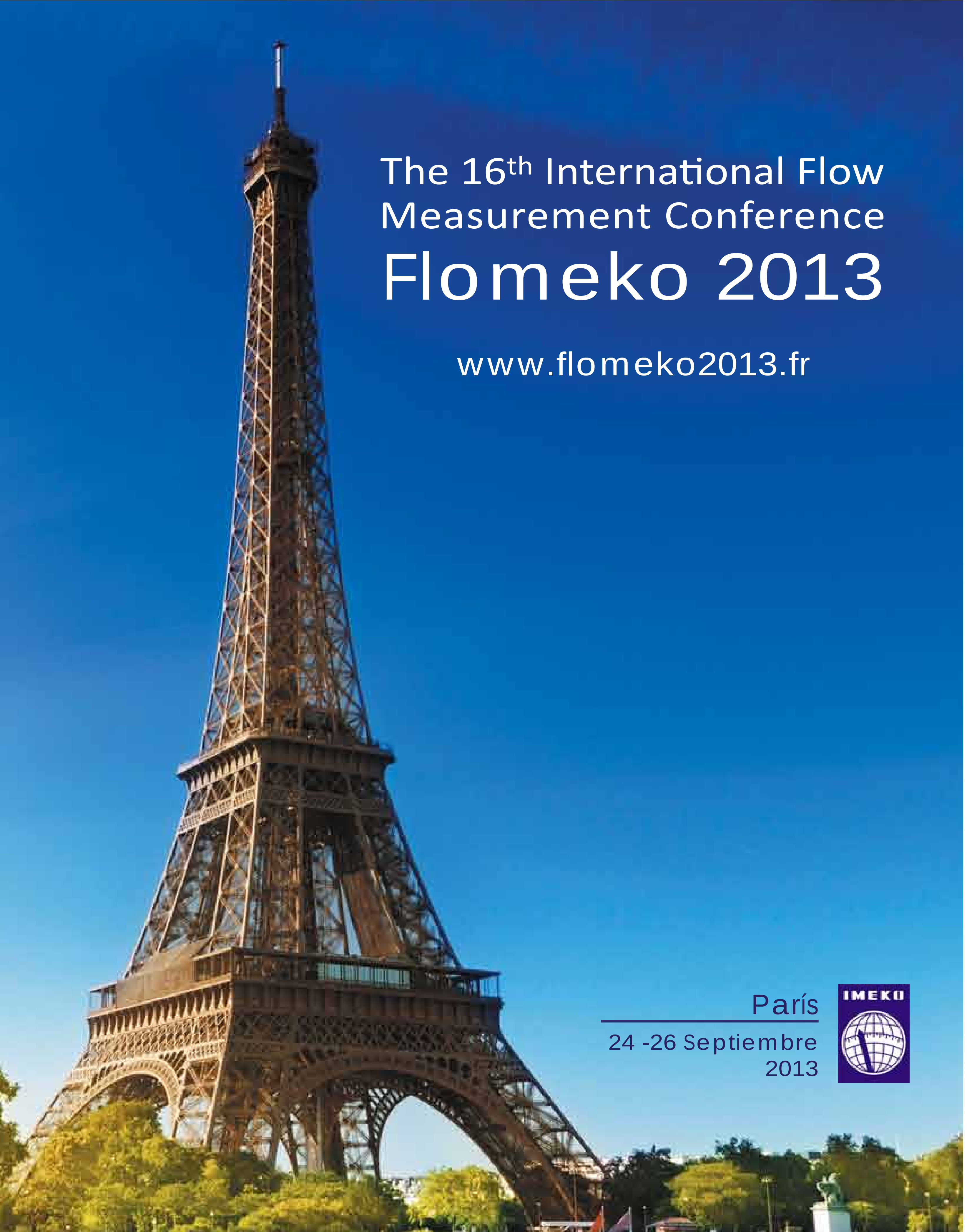

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