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North Sea FLOW Measurement Workshop

Poster Paper

A Statistical Tool To Support The Optimisation of Measurement Systems

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SUMMARY

A software tool for the optimisation of natural gas measurement systems, STO-FLOW$_{MS}$, was developed by the Corporation CDT de GAS in Colombia as a response to the need to estimate the value of uncertainty in the measurement systems utilised for custody transfer, which needed to be independent of the measurement technology involved as well as from the operational conditions and the metrological practices used in each case. The conception and development (of the tool) stemmed from the accumulated experience obtained by the Corporation in the design, diagnosis and improvement of measurement systems based on uncertainty analysis. The present work describes the scope, the structure and operation of STO-FLOW$_{MS}$, giving keys in order to understand the applicability and providing conclusions and recommendations for the further development and use of the tool.

1. INTRODUCTION

For Gas Transport Companies the measurements made at each point of custody transfer, whether for receipt or depatch, constitute one of the key processes in the objectives and development of the company, given that from these measurements:

- The balance of gas transported is controlled, between limits established by regulation and actions to optimise performance are determined within the capability of the technology used.

- The gas transport service is invoiced, together with any losses[1] (taken from the gas balance) which are distributed proportionally to the volume delivered to each client.

For the foregoing reasons, the metrological control covering the measurement systems and the results arising from the same are of vital importance to guarantee transparency in the processes associated with custody transfer, thus maintaining the confidence of clients in the transport service. As a result, CDT de GAS, conscious of the importance of these measurements together with one of the principal transporters of gas in Colombia, concerned to improve the control of its gas balances, initiated a diagnostic process which would permit the measurement systems to be assessed and opportunities for improvement identified which would, in turn, provide a better cost benefit for the gas transport company.

To this end, a statistical analysis of the gas volume transported for each client was carried out, identifying via a Pareto analysis, those measurement systems which most affected the gas balance and arriving at the conclusion that for the specific distribution network of some 227 measurement systems that 41 of them measure approximately 90% of the gas received and delivered. This presented a significant challenge, given that these systems needed to be studied in greater depth to determine the possible failures and faults in each measurement system which would then generate the best opportunities for optimum improvements to reduce losses reflected in the gas balance from the measurement system. On the other hand and even though the other 186 systems only measured 10% of the total gas volume handled by the gas pipelines, these should not be considered as less important, as for each client in particular the specific measurement system represents the 100% of the gas received or delivered as, for instance, in the case of the gas distribution companies, industrial users directly connected to the network and small volume gas producing wells.

[1] Colombian regulations permit losses or imbalances in gas transport measurement systems up to 1%.

This gas distribution network, which developed operations in the early 90's under regulations which, in Colombia, drove the massification of use of natural gas as the energy supply for electrical generation, domestic appliances industrial use and for transportation, CDT de GAS found measurement systems installed with diverse operating principles and technologies, according to the dates when the particular system was originally commissioned. These measurement systems were designed, constructed and commissioned to meet the then applicable measurement standards and under regulations which were still in the process of development, even though they continue evolving in order to align themselves with the international environment in measurement standards relating to the custody transfer of gas as well as with the national interest and to consumers who are directly or indirectly affected by the natural gas market.

In the face of this diversity of measurement systems, technologies and constituent elements (primary, secondary and tertiary), operating under various standards and regulations, it was necessary to establish a strategy and technological tools which would permit the evaluation of the diverse measurement systems aforementioned, in an efficient and effective manner using the same (common) criteria, to eventually obtain a matrix of improvements based on a level evaluation developed from engineering principles aligned with state of the art technologies and up-to-date internationally accepted standards

The strategy finally adopted consisted of a programme of inspections of the measurement systems with most impact on the gas balance, using for this purpose the Inspection Body of the corporation CDT de GAS which had recently been constituted as an autonomous, independent and transparent organisation, operating under the quality standards of ISO 17020, so guaranteeing the correct assessment of the systems in regard to the applicable standards and providing all of the information necessary to identify the weaknesses and the proposal of the improvements required by the measurement systems.

As a technological tool it was proposed to use estimations of uncertainty, associated with the gas volume measurement results as supplied by the measurement systems. It is important to note that, although such estimates have been used for more than a decade internationally and especially since the issue of the ISO GUM standards in 1995, in the Colombian standards they have not been considered an integral part of the measurement results or of the standard measurement practices in the process industries or for custody transfer of gas. This basis of comparison was, of itself, an innovation for the Gas Industry in Colombia as up to the time of the execution of the Project, subject of this paper, uncertainty had not been considered as relevant to the measurement processes for natural gas, making the resulting balances virtually useless and hindering the decision making process in regard to improvements, given that these decisions were taken generally based on quantitative and empirical appreciations without the scientific and consistent basis provided by uncertainty analysis.

So, how to estimate uncertainty with such a variance and variety of measurement technologies, constitutive elements and applicable standards? The response, which initially appears to be simple, was to develop a sufficiently robust software with suitable applicability, allowing coverage with an ample spectrum of needs and which would provide technically valid results. This eventually produced a Project within the main Project and leading to the development of the software tool STO-FLOW$_{MS}$, being described herein.

2. SCOPE OF THE SOFTWARE TOOL

Having analysed the basic requirements as well as the operability (ease of use), measurement systems subject to optimization and the validity of the expected results, the following specification or scope was defined:

- Estimate the uncertainty associated with gas volume and energy measurements in measurement systems with a diversity of technologies such as primary element, integrating the reference standard applicable to the estimation of the uncertainty – specifically ISO GUM 1995 and ISO 5168:2005

- Develop a Databook to collect and file the technical characteristics and details of the metrological performance of each of the components of the measurement system.
- Make available an efficient mechanism for the data (information) entry, without this same mechanism requiring that the user need a profound knowledge or understanding of metrology (such as mathematical models and methodology for the estimation of uncertainty).
- Integrate the applicable reference standard according to the functional technology of the individual measurement elements (primary, secondary and tertiary).
- Integrate the applicable reference standard for the calculation of natural gas properties (compressibility factor, density, specific gravity, calorific value, etc).
- Present the results of the uncertainty estimation by way of a global uncertainty budget, associated to the measurement of the volume of gas or energy and the contributions from each uncertainty source at the influence quantities.
- Make easy the optimisation of the measurement systems so assessed by way of the estimation of uncertainty and an analysis of the sensibility of the influence quantities

3. TOOL STRUCTURE

The tool was developed on Microsoft Excel 2000 ® with macros developed in Microsoft Visual 6.3, using worksheets for data entry, the execute computations and for the presentation of results (*see Fig. 1*)

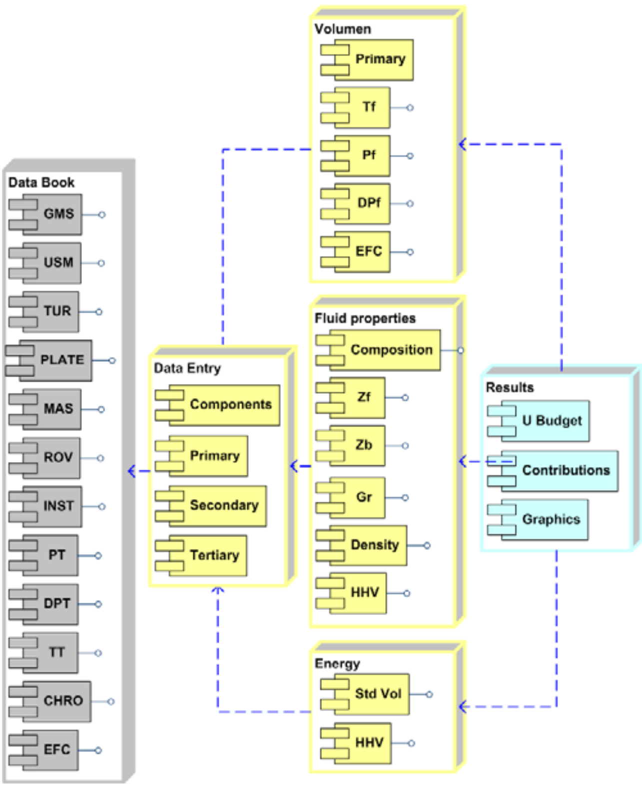


***Fig. 1** UML Diagram showing components of the Tool*

4. UNCERTAINTY ESTIMATION PROCESS

The estimation of uncertainty made by STO-FLOW$_{MS}$ was programmed following the guidelines given in the GUM and ISO 5168, integrating the knowledge relative to the sources of uncertainty which affect gas measurements, according to the technology of the components involved as well as of the operating conditions of the system. The uncertainty estimation process in simplified form is described as follows:

4.1 Measurand Definition

The target measurands are the volume or flow and the energy registered daily by the measurement system (See *Eq. 1* to *Eq. 4*). However, in order to do so the tool must estimate the associated uncertainty to multiple measurands which have influence in the computations (mathematical models), such as influence quantities (P, T, etc) and the fluid properties (Zf, Zb, Gr, HHV, etc).

All these measurands are automatically defined by STO-FLOW$_{MS}$ in function of the components installed and the characteristics of the measurement system.

Linear Meters: USM, TUR, ROV

$$Q_b = Q_f \cdot \frac{P_f}{P_b} \cdot \frac{T_b}{T_f} \cdot \frac{Z_b}{Z_f} \tag{1}$$

Differential Meters: PLATE

$$Q_b = 218{,}527 Cd\, Ev\, \varepsilon d^2 \left(\frac{T_b}{P_b}\right)\sqrt{\frac{P_f Z_b DP_f}{Gr\, Z_f T_f}} \tag{2}$$

Mass Meters: MAS

$$Q_b = Q_m \cdot \rho_b \tag{3}$$

Energy

$$E = Q_b \cdot HHV \tag{4}$$

4.2 Uncertainty Sources and Associated PDF's

For each of the influence quantities in the target measurand all the possible sources of uncertainty are listed (see *Fig. 2*), having as a basis – the reference standard, manufacturers data, metrological flow studies and the experience of the Corporation CDT de GAS.

Although there exist a large diversity of PDFs which may describe in greater or lesser confidence the performance of each source of uncertainty, it was determined that for simplicity in evaluation and interpretation only to include the most common PDF, among which are the distributions; normal, rectangular and triangular.

- **Reference Standards**

The technical standards reflect the state of the art in measurement technologies and for this reason standards were used as one of the primary source of information for the definition and estimation of the sources of uncertainty. In *Table 1* are listed the principal reference standards used.

- **Studies, Manuals and Manufacturers Data Sheets**

The manufacturers of equipment and measurement instruments analyse and characterise their products, whether through the application (to metrological entities) for model approval or from an internal quality control process. In either of these cases the results are incorporated in manuals, data sheets or white papers which, in turn, permit users to understand the correct manner and methodology for the installation, operation and maintenance in order to produce the best metrological performance. It is also possible to find technical information from the manufacturers in regard to the possible deviations and the uncertainty which these may generate when instruments are operated incorrectly or out of the recommended range or operating conditions. All this documentation was analysed, selected and integrated into the tool, considering particularly those manufacturers of frequently used equipment and listing the sources of uncertainty in order to permit modification in accordance with the characteristics and performance of the equipments assessed.

Table 1 Reference Standard [2]

Technology, Component or Property	American	International
USM	AGA 9	ISO 17089-1
TUR	AGA 7	ISO 9951
PLATE	AGA 3	ISO 5167-2
MAS	AGA 11	ISO 10790
ROV	ANSI B109.3	------
PT TT DPT	API RP 551 API 21.1	ISO 15970
CHRO	API 14.1	ISO 6974 ISO 6974 ISO 10715
EFC	API 21.1	------
Z ρ HHV	AGA 8	ISO 15970 ISO 20765-1

- **Books, Research projects and Papers on the Metrology of Gas Flow**

There exist a considerable number of operating conditions and performance of the GMS which are not considered by the reference standard(s) nor are available from the information provided by the manufacturers.

This leaves a gap which makes the quantification of certain effects (which may generate uncertainty) more difficult and for this reason an extensive survey of appropriate literature was made which permitted these sources of uncertainty to be incorporated.

Example: The performance of turbine meters is dependent upon the Reynolds number of the operating flow conditions and, as a result, there exists an uncertainty associated with this type of meter when the operating flow conditions are different from those under which the meter was calibrated. It is accepted that this dependency is a function of several factors including the specific design of the meter, the possible deviation must be considered, as not to do so may imply an excess of confidence in the values issued by the meter. In this case, a number of studies concerning the performance of turbine meters were analysed and in order to take into account changes in the operating condition Reynolds number unified criteria were defined. In the *Table 2* criteria are presented which by default may be selected to estimate the associated measurement uncertainty for turbine meters.

[2] Initially the tool was proposed to be developed solely with regard to the North America standards given that in the Colombian standards reference is made to these as the reference Standard. However, the Project was actually developed to integrate also the ISO standards in order to make the tool more universally applicable.

Table 2 Criteria for uncertainty source when operating at different condition than those of calibration [3]

Criteria	U_{Error} (k=2)	Application Condition
Excellent	0,00 %	Calibration at a condition near to that of operation ($Re_{cal} \approx Re_{ope}$)
Good	0,15 %	Difference between the calibration pressure and operating pressure, less than 400 psig
Regular	0,30 %	Difference between the calibration pressure and operating pressure, between 400 y 700 psig
Bad	0,70 %	Difference between the calibration pressure and operating pressure, greater than 700 psig

- **Knowledge and experience gained by Corporation CDT de GAS.**

The Corporation CDT de GAS has been developing since 2003 the Colombian infrastructure in regard to the measurement of gas, with which to give traceability to measurements between low value flows ($2x10^{-4}$ m^3/h) up to greater flows (4800 m^3/h), utilising primary standards such as Soap-film, Mercury sealed piston prover, bell prover, wet test meter, Dynamic displacement system (gravimetric), critical orifices, sonic nozzles, rotary meters and turbines. The design, construction, characterisation and continued improvement of this infrastructure have permitted the Corporation to develop technical strengths and gain knowledge which is then applied in the area of calibration and inspection of instruments, equipment and measurement systems. Additionally there exists an infrastructure related to the other quantities with influence on the measurement of natural gas such as: pressure, temperature, dimension (length), composition, etc. All of this has permitted the generation of a series of experiences which were taken into account in the development of the software tool.

4.3 Evaluation of Standard Uncertainty

The tool, automatically or manually permits the determination of the standard uncertainty for each identified source, independent of the level of confidence which may be attributed to the source.

As an example, the variation in the indication of a component in the reference gas during the calibration of a chromatograph, seen as a standard deviation from the mean, corresponds directly to a standard uncertainty with a normal distribution, at a level of confidence of approximately 68,27% and k=1. In this way the tool reduces all the sources of uncertainty to standard uncertainty based on a coverage factor (k), the PDF associated with the source and the original value of the uncertainty.

4.4 Combination and Correlation

The combination of the sources of uncertainty for each influence quantity and for the target measurand is made utilising the so called law of propagation of uncertainties (See *Eq. 5*), without considering the correlations between the identified influence quantities[4]. The aforegoing supposition generates a conservative effect on the uncertainty associated with the target measurand (Volume or Flow of gas and Energy) due principally to the correlation which

[3] The criteria do not constitute a catch-all and their application or otherwise may be considered or not by the user of the software tool, as the application is valid in cases of analysis of GMS in a transport system (gas pipeline) as this permits identification with a greater degree of confidence of the measurement systems which contribute the most to the gas balance uncertainty.

[4] In the cases in which it is considered necessary to evaluate and include possible correlations, an analysis of the co-variances between correlated magnitudes must be made, as it is possible to affect the Standard uncertainty of the sources by way of a correlation factor. In future versions of the software it is planned to include all the possible correlations between influence quantities of the target measurand of the software tool.

exists between Zf and Zb, as the two factors related to the compressibility depend on the same composition of gas.

$$u_c(y) = \sqrt{\sum_{i=1}^{N}\left[c_i \cdot u(x_i)\right]^2} = \sqrt{\sum_{i=1}^{N}\left[\frac{\partial f}{\partial X_i} \cdot u(x_i)\right]^2} \tag{5}$$

4.5 Expanded Uncertainty

All the properties, influence quantities and target measurands are assessed and their expanded uncertainty estimated at a confidence level of 95%. The number of degrees of freedom for each source of uncertainty is defined according to the estimation method as follows:

- Sources estimated using type A: as the number of measurements minus one, n-1.
- Sources estimated using type B: in function of the level of confidence over the sources of uncertainty, being generally, 50 or 100.

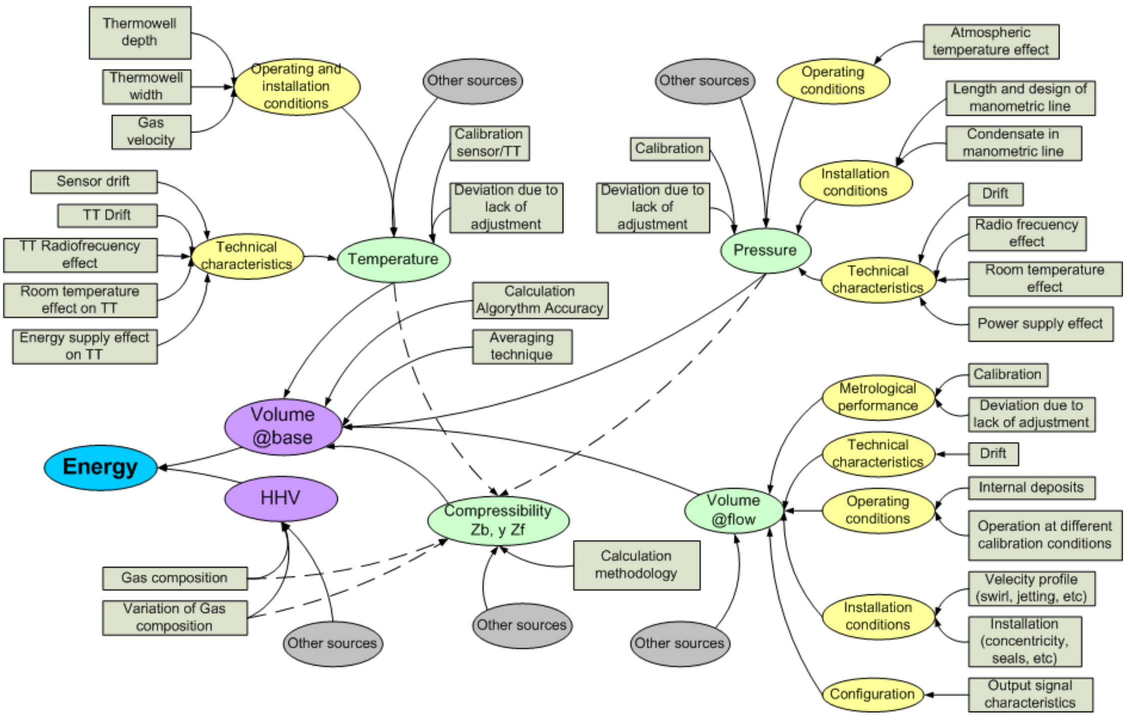


Fig. 2 Uncertainty Source Tree for the measurement of Energy using a turbine meter as primary element.

In regard to the effective degrees of freedom the Welch-Satterthwaite equation is developed.

$$\frac{1}{v_{ef}} = \sum_{i=1}^{N} \frac{\left(\frac{u_i(y)}{u_c(y)}\right)^4}{v_i} \tag{6}$$

And finally, the expanded uncertainty is obtained by multiplying the coverage factor at a confidence level of 95%, by the combined (Standard) uncertainty

$$U = u_c \cdot t_p(v_{ef}) \tag{7}$$

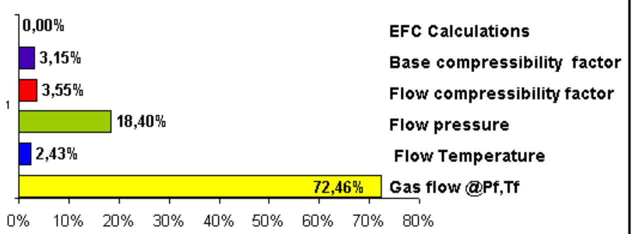
4.6 Uncertainty Budget

The presentation of results is made by way of an uncertainty budget, which is generated automatically, together with a graph of the contributions, according to target measurand (see example in *Fig. 3*). This facility permits the user to identify instantly the influence quantities with the greatest contribution to the measurement uncertainty, making it possible to access a detailed uncertainty budget with all of the uncertainty sources identified for each influence quantity

NATURAL GAS SYSTEM MEASUREMENT
UNCERTAINTY BUDGET - GAS FLOW AT BASE CONDITIONS

No.	Magnitude	Symbol	Value		u(x)	PDF	Standard Uncertainty	Sensitivity Coefficient	Contribution ui(y)	Contribution [%]
1	Gas flow @Pf,Tf	Qf	1332000	cfd	3688,1	Normal	3688,1	2,60E+01	1,33E+06	72,46%
2	Flow Temperature	Tf	1,2E+02	ºF	0,295	Normal	0,295	-5,95E+04	3,08E+08	2,43%
3	Flow pressure	Pf	4,1E+02	Psig	0,575	Normal	0,575	8,40E+04	2,33E+09	18,40%
4	Flow compressibility factor	Zf	9,7E-01	--	0,0005917	Normal	0,0006	-3,58E+07	4,49E+08	3,55%
5	Base compressibility factor	Zb	1,0E+00	--	0,0005762	Normal	0,0006	3,47E+07	3,99E+08	3,15%
6	EFC Calculations	-	-	--	-3,58E+07	Normal	-3,58E+07	1,00E+00	3,24E+05	0,00%

CONTRIBUTIONS TO THE EXPANDED UNCERTAINTY



Total Contribution ui(y)^2	Value	[%]
	1,266E+10	100,0

Description	Value	Unit
Combined Uncertainty	112523,2	CFD
Degree of freedom	89	-
Coverage factor [k]	1,99	-
Gas flow @Pb,Tb	34.594.140	MCFD
Expanded uncertainty	223.581	MCFD
Relative Exp. uncertaint	0,65	%

Fig. 3 Uncertainty Budget

5. INFORMATION / DATA ENTRY

The software tool requires a great amount of information from the GMS in order to estimate the measurement uncertainty. It is necessary for the user to be able to count upon the following among others:

- Data sheet and Manual of each equipment and instrument from the GMS.
- Current and previous Calibration Certificates of each instrument and component of the GMS.
- Configuration file, Log and audit trail of the EFC.
- Hourly and daily record of the process variables, pressure, temperature, flow, etc.
- Record of the gas composition according to the configuration of the chromatograph.
- Isometric of the GMS.
- Gas Composition Certificate of the reference Gas used to calibrate the chromatograph.

In order to facilitate the systematic and ordered entry of this information the tool has the following two options:

Option 1: Importation of data from the Databook
Option 2: Information entry direct from the entry form.

5.1 Description of the Databook

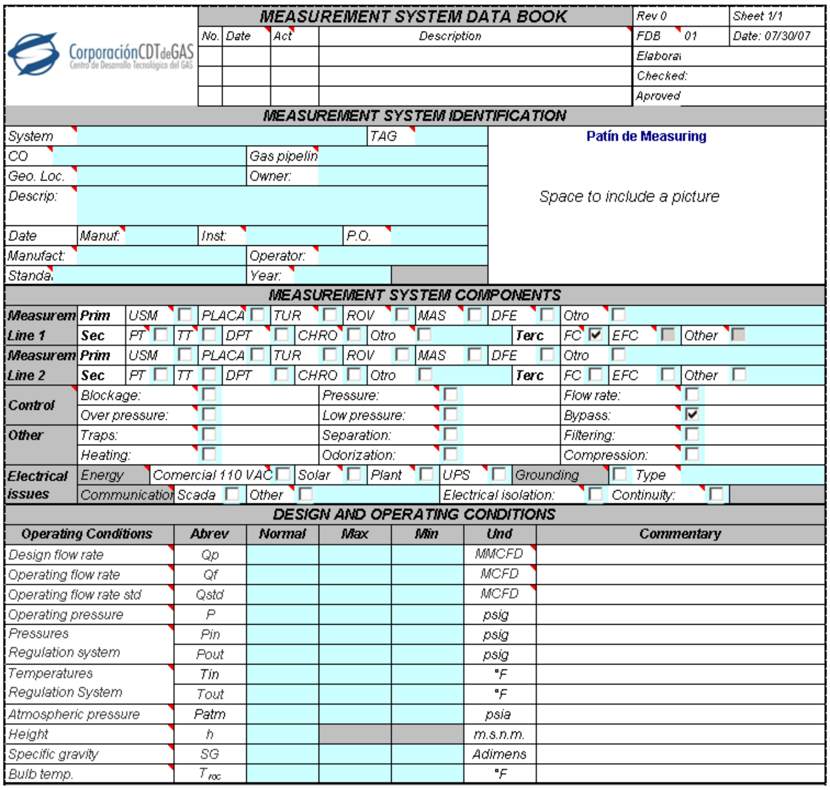
The Databook is an extended form which consists of 13 Excel® sheets, which have been designed for the collection of data and information in an intuitive manner, so that it is only necessary to access up to six (6) sheets in the case of the most complex GMS or for the greatest quantity of components.

In the *Table 3* the sheets which comprise the Databook are briefly described as well as the objectives of the same.

The Excel sheets which make up the DataBook are arranged so as to request such information as to ensure that each element of the measurement system is uniquely and properly defined along with its principal technical characteristics and metrological performance.

Table 3 Sheets which make up the Databook

Sheet	General description of the Sheet
GMS	Identification, components, operational conditions and the design of the measurement system. Each Sheet summarises the characteristics of the GMS and associated systems such as regulation, filtration, etc.
INST	Specification and technical characteristics of the meter tubes and a description of the installation of the GMS.
USM	Identification, configuration and technical characteristics of the USM meters, associated with metering system.
PLATE	Identification, configuration and technical characteristics of the orifice plate type meters associated with metering system.
PDT	Identification, configuration and technical characteristics of the turbine and positive displacement meters (rotary and diaphragm) associated with the GMS.
MAS	Identification, configuration and technical characteristics of the Mass Meters (Coriolis), associated with the GMS.
PT-DPT	Identification, configuration and technical characteristics of the instruments for the measurement of pressure (manometric), absolute or differential, associated with the GMS.
TT	Identification, configuration and technical characteristics of the instruments for the measurement of temperature, associated with the GMS.
CHRO	Identification, configuration and technical characteristics of the chromatograph associated with the GMS.
EFC	Identification, configuration and technical characteristics of the flow computer associated with the GMS.



CorporaciónCDTdeGAS	MEASUREMENT SYSTEM DATA BOOK					Rev 0	Sheet 1/1
	No.	Date	Act	Description		FDB 01	Date: 07/30/07
						Elabora:	
						Checked:	
						Aproved	

MEASUREMENT SYSTEM IDENTIFICATION

System		TAG	Patín de Measuring
CO		Gas pipelin	
Geo. Loc.		Owner:	
Descrip:			Space to include a picture
Date	Manuf.	Inst.	P.O.
Manufact:		Operator:	
Standa.		Year:	

MEASUREMENT SYSTEM COMPONENTS

Measurem Line 1	Prim	USM ☐	PLACA ☐	TUR ☐	ROV ☐	MAS ☐	DFE ☐	Otro ☐		
	Sec	PT ☐	TT ☐	DPT ☐	CHRO ☐	Otro ☐	Terc	FC ☑	EFC ☐	Other ☐
Measurem Line 2	Prim	USM ☐	PLACA ☐	TUR ☐	ROV ☐	MAS ☐	DFE ☐	Otro ☐		
	Sec	PT ☐	TT ☐	DPT ☐	CHRO ☐	Otro ☐	Terc	FC ☐	EFC ☐	Other ☐
Control	Blockage: ☐		Pressure: ☐				Flow rate: ☐			
	Over pressure: ☐		Low pressure: ☐				Bypass: ☑			
Other	Traps: ☐		Separation: ☐				Filtering: ☐			
	Heating: ☐		Odorization: ☐				Compression: ☐			
Electrical issues	Energy	Comercial 110 VAC ☐	Solar ☐	Plant ☐	UPS ☐	Grounding ☐	Type			
	Communication	Scada ☐	Other ☐		Electrical isolation: ☐		Continuity: ☐			

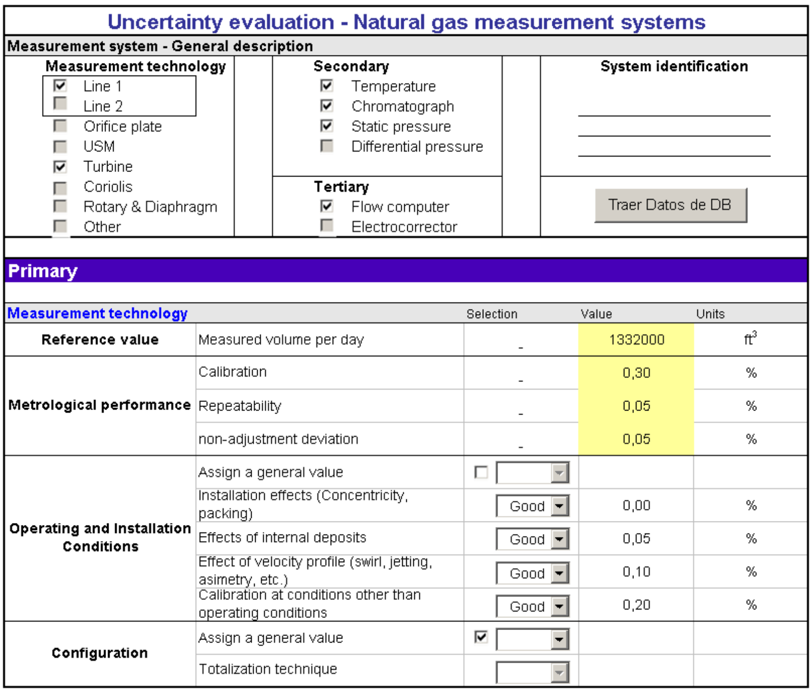
DESIGN AND OPERATING CONDITIONS

Operating Conditions	Abrev	Normal	Max	Min	Und	Commentary
Design flow rate	Qp				MMCFD	
Operating flow rate	Qf				MCFD	
Operating flow rate std	Qstd				MCFD	
Operating pressure	P				psig	
Pressures	Pin				psig	
Regulation system	Pout				psig	
Temperatures	Tin				°F	
Regulation System	Tout				°F	
Atmospheric pressure	Patm				psia	
Height	h				m.s.n.m.	
Specific gravity	SG				Adimens	
Bulb temp.	T_{roc}				°F	

Fig. 4 DataBook – GMS Sheet

5.2 Entry Form

As a second option it is possible to enter directly information from the GMS in the Entry Form of the software tool (see
Fig. 5), in which case an assessment and/or prior knowledge on the part of the user is needed in regard to certain characteristics of the performance of the components of the system.



Uncertainty evaluation - Natural gas measurement systems

Measurement system - General description

Measurement technology	Secondary	System identification
☑ Line 1	☑ Temperature	
☐ Line 2	☑ Chromatograph	
☐ Orifice plate	☑ Static pressure	
☐ USM	☐ Differential pressure	
☑ Turbine	**Tertiary**	Traer Datos de DB
☐ Coriolis	☑ Flow computer	
☐ Rotary & Diaphragm	☐ Electrocorrector	
☐ Other		

Primary

Measurement technology		Selection	Value	Units
Reference value	Measured volume per day	-	1332000	ft³
Metrological performance	Calibration	-	0,30	%
	Repeatability	-	0,05	%
	non-adjustment deviation	-	0,05	%
Operating and Installation Conditions	Assign a general value	☐		
	Installation effects (Concentricity, packing)	Good	0,00	%
	Effects of internal deposits	Good	0,05	%
	Effect of velocity profile (swirl, jetting, asimetry, etc.)	Good	0,10	%
	Calibration at conditions other than operating conditions	Good	0,20	%
Configuration	Assign a general value	☑		
	Totalization technique			

Fig. 5 Entry Form

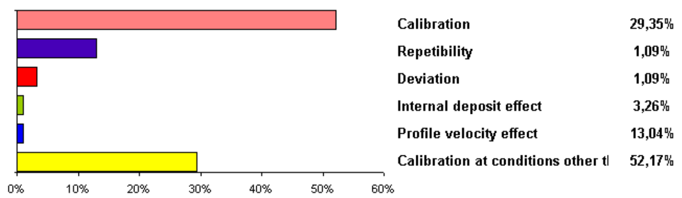
6. RESULTS PROVIDED BY THE SOFTWARE TOOL

The principal results provided by the software are the uncertainty budget and the contributions of the various influence quantities, which example may be seen in *Fig. 3*. Additionally it is possible to obtain for each influence quantity an uncertainty budget and sensibility analysis considering all the sources of uncertainty. In this way it is possible to control not only the quantities with greatest impact on the overall measurement uncertainty but also those sources which generate the same.

UNCERTAINTY BUDGET - GAS FLOW AT LINE CONDITIONS

	Magnitude / Source	Symbol	Information	Value		Original Uncertainty		PDF	Standard Unc u(xi)		c_i	Contrib. $u_i(y)$	Contrib. $u_i^2(y)$	Contrib. $u_i^2(y)$	Contrib. [%]
1	Primary	MF	-	1332000	CFD	-	-	Normal	3688	CFD	1,00				
1.1	**Metrology performance**	UDM-MF													
1.1.1	Calibration	UCal-MF	Calibration certificate			3996	CFD	Normal (k=2)	1998	CFD		1998,0	50	3,99E+06	29,35%
1.1.2	Repetibility	URep-MF	Calibration certificate			666	CFD	Rectangular	385	CFD		384,5	50	1,48E+05	1,09%
1.1.3	Deviation	UCA-MF	Calibration certificate			666	CFD	Rectangular	385	CFD		384,5	50	1,48E+05	1,09%
1.3	**Technical Specification**	UCT-MF													
1.4	**Installation and operating conditions**	UCIO-MF													
1.4.2	Internal deposit effect	UDI-MF	Scientific Literature			666	CFD	Normal (k=1)	666	CFD		666,0	50	4,44E+05	3,26%
1.4.3	Profile velocity effect	UPV-MF	Scientific Literature			1332	CFD	Normal (k=1)	1332	CFD		1332,0	50	1,77E+06	13,04%
1.4.4	Calibration at conditions other than operating conditions	UCC-MF	Scientific Literature			2664	CFD	Normal (k=1)	2664	CFD		2664,0	50	7,10E+06	52,17%
1.5	**Configuration**	UConf-MF													

CONTRIBUTIONS TO THE EXPANDED UNCERTAINTY



Total Contribution ui(y)^2	Value	[%]
	1,36E+07	100%

Description	Valor	Unid
Combined Uncertainty	3688,1	MCFD
Degree of freedom	132	-
Coverage factor [k]	1,978	-
Gas flow @Pb,Tb	1332000	MCFD
Expanded uncertainty	7296	MCFD
Relative Exp. uncertainty	0,55	%

Fig. 6 Entry Form

7. OPTIMISATION PROCESS

The optimisation process for a measurement system and in consequence of the results produced by the same, implies the application of a minimum investment in the improvement of the GMS in order to obtain measurement results within the level of desired uncertainty which in turn has been determined between the interested parties in the custody transfer process, in other words the stakeholders who seek to reduce the economic exposure associated with an inadequate uncertainty level.

The level of uncertainty required is generally inferior to the limits of uncertainty specified by the applicable regulation but the real value is limited by the state of the art in instrumentation and equipment technologies as well as the cost of implementation, maintenance and metrological assurance of the GMS.

As a result, in order to initiate the optimisation process (see *Fig. 7*), the system is evaluated in order to determine an initial and actual uncertainty level obtained from the application of the software tool, identifying through the process those sources with greatest impact on the uncertainty of the volume of natural gas or energy measured by the GMS. To reduce the measurement uncertainty several options are open:

- Change in the metrological assurance practices
- Reconfiguration of components at the software level
- Change or upgrade of components

- Installation of new components
- Change in the operation or installation conditions

For these scenarios there exist a number of activities which should commence with the proposition to use those which have greatest positive impact for least cost. Finally the system uncertainty is re-assessed to compare the actual or new value with the desired level in an iterative process executed by the user in function of their experience, the available investment and any technological limitations to the improvements to be implemented.

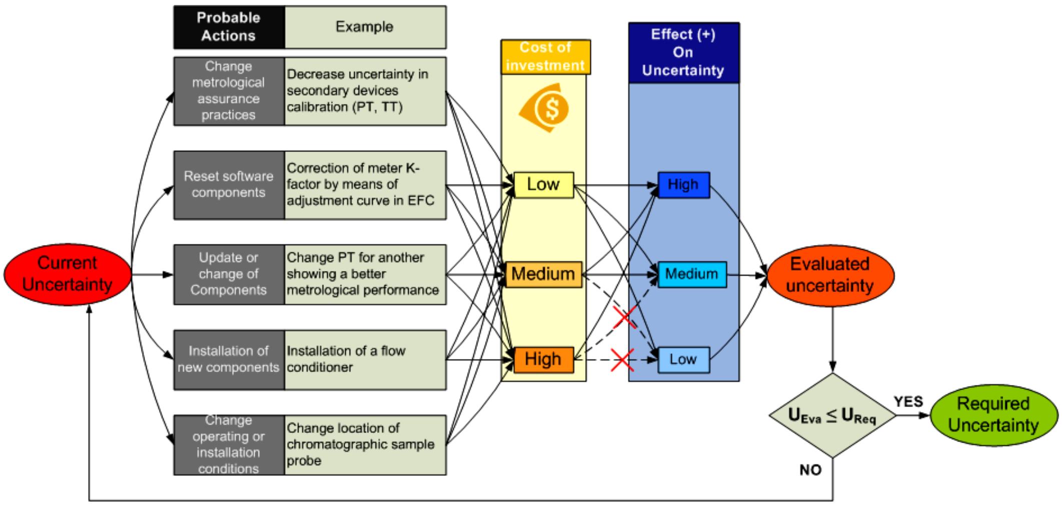


Fig. 7 GMS Optimisation Process

8. CONCLUSIONS

- The development and application of the software tool has permitted significant saving in the time and cost needed to improve the natural gas measurement systems which have been analysed by CDT de GAS. It has also permitted design of new measurement systems based on uncertainty analysis in line with the requirements and expectations of clients.
- Uncertainty (analysis) constitutes one of the most important tools for the decision making process involved in custody transfer systems, their control and continuous improvement. Additionally, uncertainty analysis is necessary to control gas balances by way of balance conciliation.
- The quality of information used to effect the estimates of uncertainty through the use of the software tool is key to obtaining valid results which, in turn, allow the economic risk associated with the investments in the improvement of the GMS to be reduced.
- In the GMS various effects are present dependent upon operating conditions, installation, fluid quality and composition, component configuration, etc., each of which is difficult to estimate and for which adequate studies still do not exist which would allow a better degree of confidence in such sources of uncertainty added by these effects which impact on the performance of the measurement system.

9. RECOMMENDATIONS

- From the process of design of measurement systems it is necessary to apply the reference standards in accordance with measurement technology to be used, avoiding operating conditions outside the specified limits for which no experimental data is available which will allow the uncertainty to be determined
- Study and incorporate into the tool sources of uncertainty contributed by the metrologist who makes the uncertainty estimate and which may influence the results, whether conservative or not, in respect to his experience and personal knowledge.

- Extend the standard references of the tool to fully include ISO standards and so permit its generalised use in international applications of natural gas custody transfer.
- Continue the development of the tool in order to involve custody transfer applications related to liquid hydrocarbons in accordance to API and ISO standards.

10. ABBREVIATIONS

GMS	Gas measurement system
USM	Ultrasonic meter
TUR	Turbine meter
PLATE	Orifice meter
MAS	Coriolis meter
ROV	Rotative meter
INST	Installation Conditions
PT	Pressure transmitter
DPT	Differential pressure transmitter
TT	Temperature Transmitter
CHRO	Chromatograph
EFC	Electronic Flow Computer
Q_f	Flow@Pf,Tf
Q_b	Flow base
T_f	Flow Temperature

P_f	Flow pressure
DP_f	Flow differential pressure
Z_f	Flow compressibility factor
Z_b	Base compressibility factor
Gr	Specify Gravity
Cd	Discharge Coefficient
Ev	Approach velocity factor
ε	Expansibility factor
D	Orifice diameter
HHV	High Heating Value
PDF	Probability Density Function
Re	Reynold number
CFD	Cubit feet day
MCFD	Thousand cubic feet /day

11. REFERENCES

As already described in this paper the development of the software tool utilised various standards, regulations and studies and so given the great number of these only the main references are listed here.

[1] Resolución No. 071 de 1999 “Reglamento Único de Transporte de Gas Natural”, *CREG.*

[2] ISO-GUM Guide to the expression uncertainty measurement

[3] ISO 5168, Measurement of fluid flow- Procedures for the evaluation of uncertainties, 2005.

[4] AGA 9, Measurement of gas by multipath ultrasonic Meters, 1998.

[5] AGA 7, Measurement of natural gas by turbine meters, 2007.

[6] AGA 3, Concentric, Square-Edged Orifice meters. 2000.

[7] AGA 11, Measurement of natural gas by Coriolis Meters, 2003.

[8] ANSI B109.3 Rotary type gas displacement meters, 2000.

[9] API RP 551 Process Measurement Instrumentation, 1993.

[10] API 21.1 Flow Measurement Using Electronic Metering System- Electronic Gas Measurement, 1993.

[11] API 14.1 Collecting and handling of Natural Gas Samples for Custody Transfer, 2006.

[12] API 21.1 Chapter 21, Section 1-Electronic Gas Measurement, 1993.

[13] AGA 8, Compressibility factors of natural gas and other related hydrocarbon gases, 1992.