EURAMET Key Comparison EURAMET M-FF-K6b

# Comparison of the Primary (National) Standards of Low Pressure Gas Flow

## TECHNICAL REPORT

*LABORATORY OF FLUID FLOW*
**HELLENIC INSTITUTE OF METROLOGY**

JANUARY 2011

## Abstract

*This work comprises the contribution of the Hellenic Institute of Metrology (EIM) to* EURAMET Key Comparison EURAMET M-FF-K6b which aims to compare the primary (national) standards of low pressure gas flow within several European National Metrology Institutes. *The experimental procedure applied as well as the equipment used and the environmental conditions prevailing during calibration are described. The flow rate determined by the reference gas flow facility used as well as the percentage error in the flow rate between the transfer standard and the reference facility are reported. A detailed analysis of the main uncertainty components associated with the measurement of the flow rate is also given.*

**HELLENIC INSTITUTE OF METROLOGY**
**Mechanical Measurements Department**
***Fluid Flow & Volume Laboratory***
Dr. Zoe Metaxiotou, Laboratory Head

Postal address:
Industrial Area of Thessaloniki
Block 45, Sindos
GR-57 022
GREECE
Phone: +30 2310 56 99 62, +30 2310 56 99 99
Fax: +30 2310 56 99 96

## Table of Contents

## 1. Description of Test Facility

The low pressure gas flow facility of EIM used in this project consists of a CAL-BENCH Bell Prover System, SIERRA INSTRUMENTS, INC covering a flow range from 15 l/min to 700 l/min (0,9 – 42 $m^3/h$), respectively. The general principle of operation of the facility is briefly described below.

### Cal-Bench Bell Prover System, SIERRA INSTRUMENTS, INC

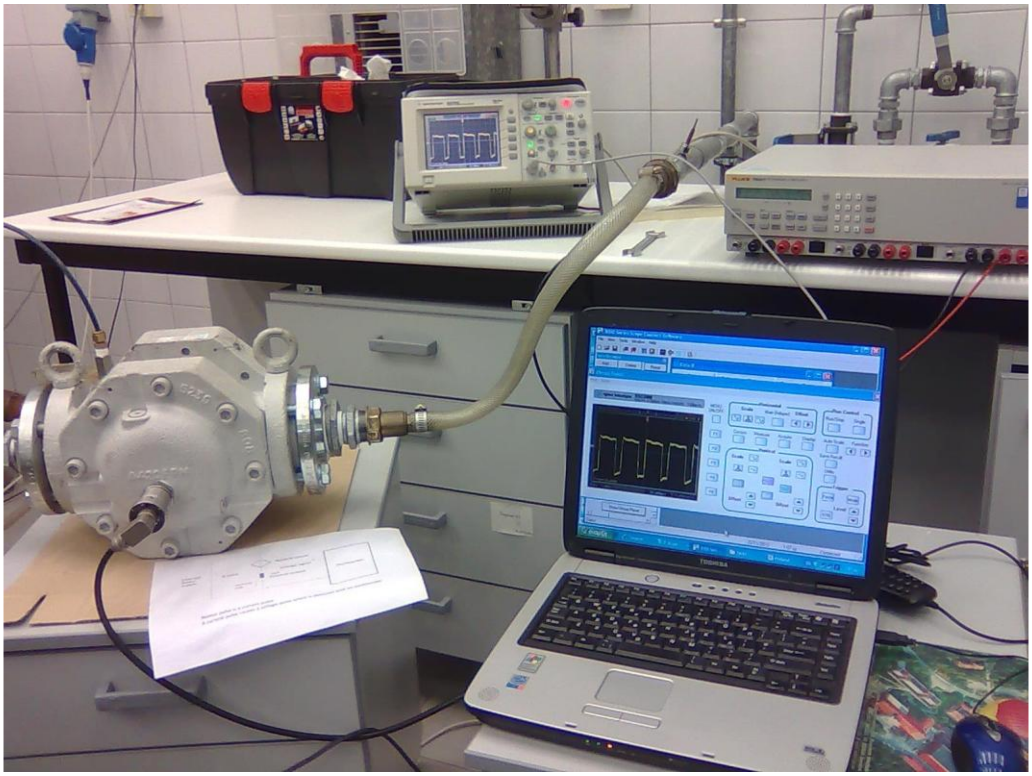
A stainless steel bell of a known and consistent volume is suspended in a low vapor oil-filled chamber. As gas flows through the device under test and enters the prover the bell is displaced. The bell is counter balanced throughout its travel by two counter weights suspended on chains. Thus as bell rises additional segments of chain pass over the pulleys, achieving neutral buoyancy in all positions. A small gauge wire is connected to the top of the bell and connects to a linear encoder system, which measures the bell's location as it is displaced by the gas flowing into the chamber. The system is equipped with automated inputs of temperature and back pressure measurements and corrects automatically the measured flow rate to user defined standard pressure and temperature conditions [1].

.

**Figure 1.** Partial view (1) of the experimental arrangement with Bell Prover reference facility.

The laboratory humidity and temperature were recorded with a Rotronic hydrometer with resolution 0,1% and 0,1 $^{o}$C , respectively. Atmospheric pressure was recorded with a Lufft analog precision barometer with a resolution 0,5 mbar.

The reference temperature was measured downstream the rotary gas meter (TS) with a 4 wire Pt-100 temperature sensor attached to an Agilent multi meter. The reference pressure from the rotary gas meter was measured with a MENSOR pressure transducer.



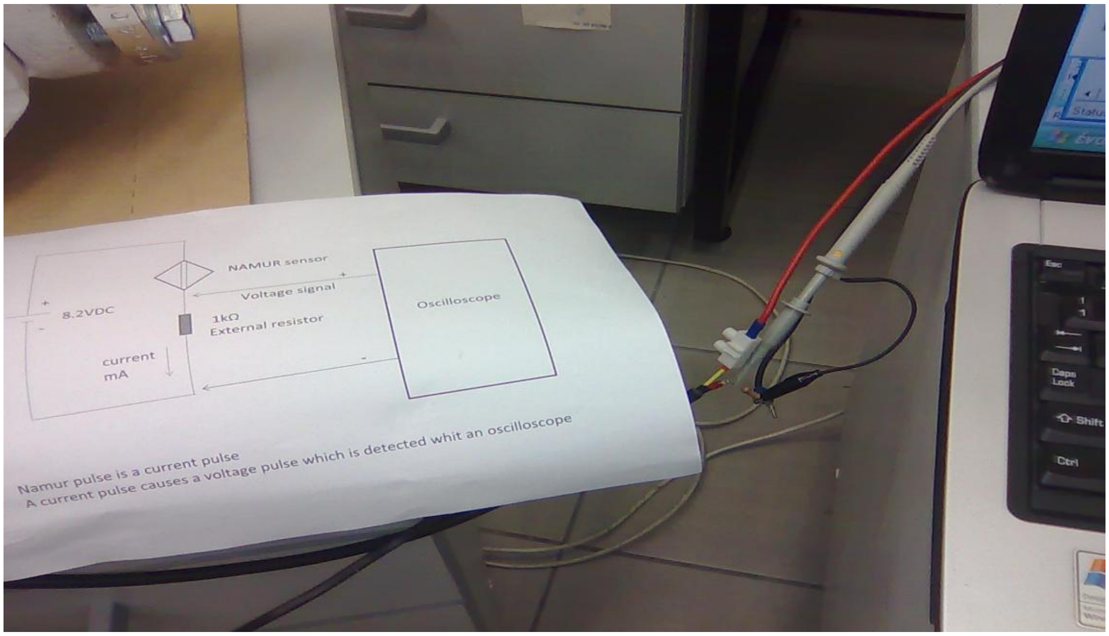
.

**Figure 2.** Partial view (2) of the experimental arrangement and auxiliary equipment used with Bell Prover reference facility.

The signal transducer from the rotary gas meter was a NAMUR type transducer which gives a current pulse signal. When powered with 8,2 V over a 1kΩ external resistor this current signal is converted to a voltage pulse signal which can be detected by an oscilloscope (Figure 3).

The pulses from the rotary gas meter were recorded by an Agilent Oscilloscope and were used in order to calculate the actual flow rate of the rotary meter during calibration.

All equipment used as well as the rotary gas transfer standard was thermally equilibrated in the laboratory at least 48 hours before actual measurements. Laboratory temperature was stabilized to 23 $^{o}$ C. Fluctuations not larger than ± 0,3 $^{o}$ C were recorded during a working day. During all tests dried, clean, compressed air was used as calibration gas.



Namur pulse is a current pulse
A current pulse causes a voltage pulse which is detected whit an oscilloscope

**Figure 3.** Schematic view of the Namur signal transformation from current pulse signal to voltage pulse signal.

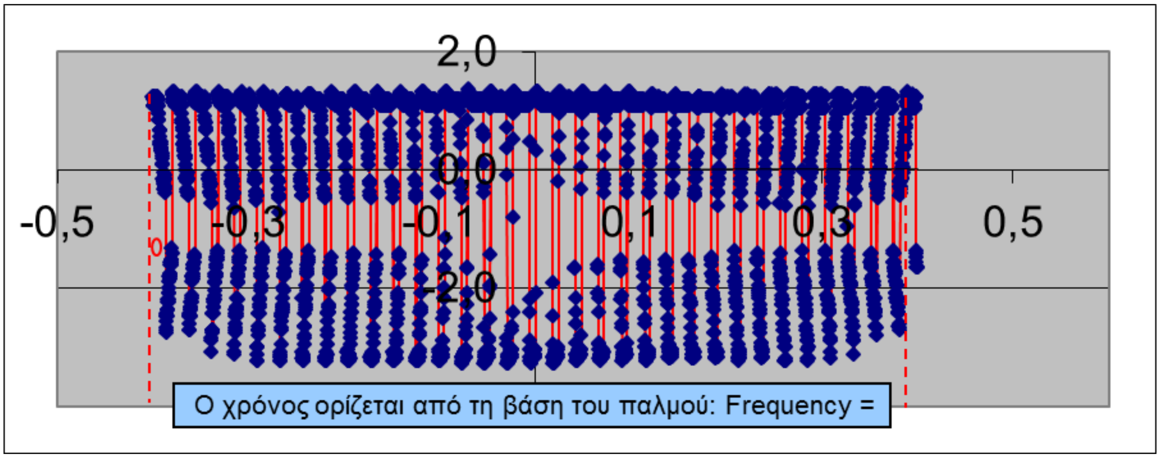


**Figure 4.** Typical voltage pulse signal as recorded by the oscilloscope.

## 2. Preparation and Experimental

Upon receipt, the package casing of the transfer package was checked for damage. The contents were checked against the contents list and were fount to be in accordance with the listed items. No damage was observed either in the casing or in the transfer standard (TS).

The reference facility used in this project is a volumetric device working on a positive displacement principle. Therefore, the reference flow rate was expressed in [sm$^3$/h] which means that the actual flow rate was corrected to user defined STP conditions. In this case the standard conditions were 101325 Pa and 20 $^o$C. The flow rate measured by the TS was also corrected to standard conditions and therefore also expressed in [sm$^3$/h].

The laboratory reference standard could not achieve the full range of flow rates prescribed in the technical protocol. Therefore, the flow rates tested were the following: 6,6 m$^3$/h, 9,1 m$^3$/h, 13,1 m$^3$/h, 16 m$^3$/h, 24 m$^3$/h, 32 m$^3$/h, and 40 m$^3$/h. Before the beginning of each test of the gas meter was warming up for approx. 20 minutes in high flow rate in order to stabilise the operation of the internal mechanical parts.

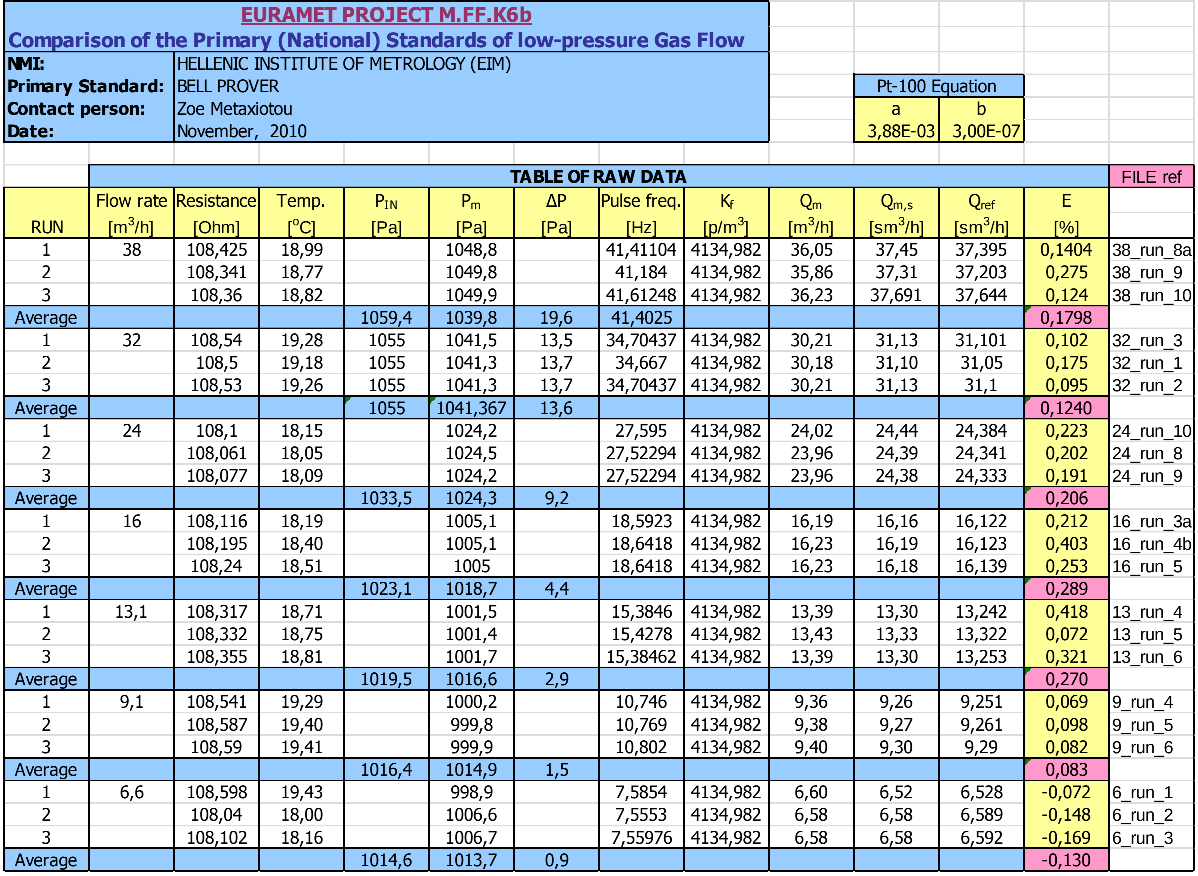
## 3. Calibration Method

All measurements were conducted by one person. The calibration method applied [2] is the one used in regular calibrations performed in the laboratory except the meter signal processing which in this case was adapted to the specifications of the TS.

## 4. Results

All experimental raw data have been recorded in the suggested by the pilot laboratory experimental protocol which has been slightly modified to fit the specific working conditions of the used reference flow facility. For each tested flow rate three repeats were conducted. The raw data are shown in Table 1. The measured error of the rotary gas meter as a function of the tested flow rated is depicted in Figure 5.

**Table 1.** Experimental raw data



EURAMET PROJECT M.FF.K6b

Comparison of the Primary (National) Standards of low-pressure Gas Flow

**NMI:** HELLENIC INSTITUTE OF METROLOGY (EIM)

**Primary Standard:** BELL PROVER

**Contact person:** Zoe Metaxiotou

**Date:** November, 2010

| Pt-100 Equation | |
|---|---|
| a | b |
| 3,88E-03 | 3,00E-07 |

TABLE OF RAW DATA

| RUN | Flow rate [m$^3$/h] | Resistance [Ohm] | Temp. [$^o$C] | $P_{IN}$ [Pa] | $P_m$ [Pa] | ΔP [Pa] | Pulse freq. [Hz] | $K_f$ [p/m$^3$] | $Q_m$ [m$^3$/h] | $Q_{m,s}$ [sm$^3$/h] | $Q_{ref}$ [sm$^3$/h] | E [%] | FILE ref |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 38 | 108,425 | 18,99 | | 1048,8 | | 41,41104 | 4134,982 | 36,05 | 37,45 | 37,395 | 0,1404 | 38_run_8a |
| 2 | | 108,341 | 18,77 | | 1049,8 | | 41,184 | 4134,982 | 35,86 | 37,31 | 37,203 | 0,275 | 38_run_9 |
| 3 | | 108,36 | 18,82 | | 1049,9 | | 41,61248 | 4134,982 | 36,23 | 37,691 | 37,644 | 0,124 | 38_run_10 |
| Average | | | | 1059,4 | 1039,8 | 19,6 | 41,4025 | | | | | 0,1798 | |
| 1 | 32 | 108,54 | 19,28 | 1055 | 1041,5 | 13,5 | 34,70437 | 4134,982 | 30,21 | 31,13 | 31,101 | 0,102 | 32_run_3 |
| 2 | | 108,5 | 19,18 | 1055 | 1041,3 | 13,7 | 34,667 | 4134,982 | 30,18 | 31,10 | 31,05 | 0,175 | 32_run_1 |
| 3 | | 108,53 | 19,26 | 1055 | 1041,3 | 13,7 | 34,70437 | 4134,982 | 30,21 | 31,13 | 31,1 | 0,095 | 32_run_2 |
| Average | | | | 1055 | 1041,367 | 13,6 | | | | | | 0,1240 | |
| 1 | 24 | 108,1 | 18,15 | | 1024,2 | | 27,595 | 4134,982 | 24,02 | 24,44 | 24,384 | 0,223 | 24_run_10 |
| 2 | | 108,061 | 18,05 | | 1024,5 | | 27,52294 | 4134,982 | 23,96 | 24,39 | 24,341 | 0,202 | 24_run_8 |
| 3 | | 108,077 | 18,09 | | 1024,2 | | 27,52294 | 4134,982 | 23,96 | 24,38 | 24,333 | 0,191 | 24_run_9 |
| Average | | | | 1033,5 | 1024,3 | 9,2 | | | | | | 0,206 | |
| 1 | 16 | 108,116 | 18,19 | | 1005,1 | | 18,5923 | 4134,982 | 16,19 | 16,16 | 16,122 | 0,212 | 16_run_3a |
| 2 | | 108,195 | 18,40 | | 1005,1 | | 18,6418 | 4134,982 | 16,23 | 16,19 | 16,123 | 0,403 | 16_run_4b |
| 3 | | 108,24 | 18,51 | | 1005 | | 18,6418 | 4134,982 | 16,23 | 16,18 | 16,139 | 0,253 | 16_run_5 |
| Average | | | | 1023,1 | 1018,7 | 4,4 | | | | | | 0,289 | |
| 1 | 13,1 | 108,317 | 18,71 | | 1001,5 | | 15,3846 | 4134,982 | 13,39 | 13,30 | 13,242 | 0,418 | 13_run_4 |
| 2 | | 108,332 | 18,75 | | 1001,4 | | 15,4278 | 4134,982 | 13,43 | 13,33 | 13,322 | 0,072 | 13_run_5 |
| 3 | | 108,355 | 18,81 | | 1001,7 | | 15,38462 | 4134,982 | 13,39 | 13,30 | 13,253 | 0,321 | 13_run_6 |
| Average | | | | 1019,5 | 1016,6 | 2,9 | | | | | | 0,270 | |
| 1 | 9,1 | 108,541 | 19,29 | | 1000,2 | | 10,746 | 4134,982 | 9,36 | 9,26 | 9,251 | 0,069 | 9_run_4 |
| 2 | | 108,587 | 19,40 | | 999,8 | | 10,769 | 4134,982 | 9,38 | 9,27 | 9,261 | 0,098 | 9_run_5 |
| 3 | | 108,59 | 19,41 | | 999,9 | | 10,802 | 4134,982 | 9,40 | 9,30 | 9,29 | 0,082 | 9_run_6 |
| Average | | | | 1016,4 | 1014,9 | 1,5 | | | | | | 0,083 | |
| 1 | 6,6 | 108,598 | 19,43 | | 998,9 | | 7,5854 | 4134,982 | 6,60 | 6,52 | 6,528 | -0,072 | 6_run_1 |
| 2 | | 108,04 | 18,00 | | 1006,6 | | 7,5553 | 4134,982 | 6,58 | 6,58 | 6,589 | -0,148 | 6_run_2 |
| 3 | | 108,102 | 18,16 | | 1006,7 | | 7,55976 | 4134,982 | 6,58 | 6,58 | 6,592 | -0,169 | 6_run_3 |
| Average | | | | 1014,6 | 1013,7 | 0,9 | | | | | | -0,130 | |

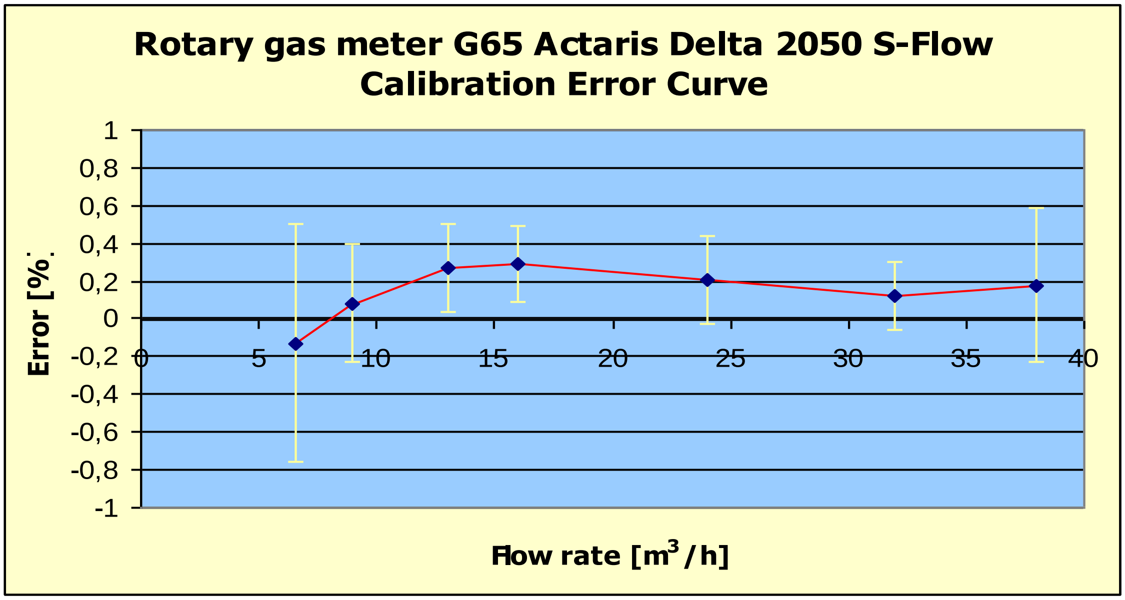


**Figure 5**. Calibration error curve of Actaris rotary gas meter transfer standard

## 5. Uncertainty Analysis

The results of this exercise accompanied by the corresponded uncertainty are given in Table 2.

**Table 2.** Calibration results for Actaris Delta S-flow G65 rotary gas meter

| Flow rate of the transfer standard | Absolute pressure in the transfer standard | Temperature in the transfer standard | Pressure loss of the transfer standard | Error of the transfer standard | Expanded uncertainty of measurement *U* (*k*=2) |
|---|---|---|---|---|---|
| ($sm^3/h$) | (Pa) | (°C) | (Pa) | (%) | (%) |
| 37,5 | 1049,4 | 18,9 | 19,6 | 0,18 | 0,41 |
| 31,1 | 1041,4 | 19,2 | 13,6 | 0,12 | 0,18 |
| 24,4 | 1024,3 | 18,1 | 9,2 | 0,21 | 0,23 |
| 16,2 | 1005,1 | 18,4 | 4,4 | 0,29 | 0,2 |
| 13,3 | 1001,5 | 18,8 | 2,9 | 0,27 | 0,23 |
| 9,3 | 1000 | 19,4 | 1,5 | 0,08 | 0,31 |
| 6,6 | 1004,1 | 18,5 | 0,9 | -0,13 | 0,63 |

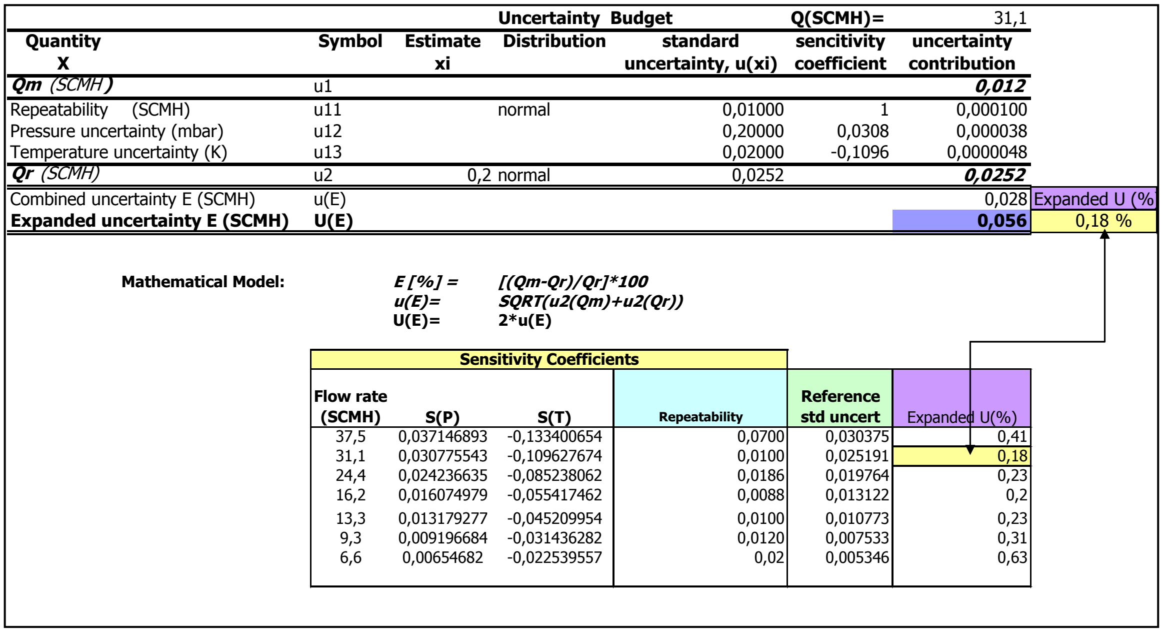
Reported is the expanded uncertainty, U(E), in the value of the calculated percentage error, E, in the flow rate between the TS and the reference, which results from the combined standard uncertainty, u(E), by multiplication with the coverage factor k = 2. It has been evaluated according to the «Guide to the expression of uncertainty in measurement» (ISO, Geneva, 1995). The value of the measured quantity, E, is found within the attributed interval with a probability of approximately 95%.

An example of a detailed evaluation of the individual uncertainty terms as well as their combination to the total uncertainty is documented in Table 3 for a typical flow rate of Q = 31,1 [$m^3/h$].

The reported expanded uncertainty, U(E), refers to the value of the error (%) for each tested flow rate and arises from the uncertainty in the calculated flow rate of the TS and the reference facility, respectively, according to the formula:

$$U(E) = 2 \times u(E) = 2 \times \sqrt{u^2(Q_m) + u^2(Q_r)} \qquad (1)$$

where:
*u(E)* is the combined standard uncertainty in the value of the error, E,
$u(Q_m)$ is the combined standard uncertainty in the flow rate of the TS,
$u(Q_r)$ is the combined standard uncertainty in the indication of the reference.



|  |  |  | Uncertainty Budget |  | Q(SCMH)= | 31,1 |  |
|---|---|---|---|---|---|---|---|
| **Quantity X** | **Symbol** | **Estimate xi** | **Distribution** | **standard uncertainty, u(xi)** | **sencitivity coefficient** | **uncertainty contribution** |  |
| ***Qm*** *(SCMH)* | u1 |  |  |  |  | ***0,012*** |  |
| Repeatability (SCMH) | u11 |  | normal | 0,01000 | 1 | 0,000100 |  |
| Pressure uncertainty (mbar) | u12 |  |  | 0,20000 | 0,0308 | 0,000038 |  |
| Temperature uncertainty (K) | u13 |  |  | 0,02000 | -0,1096 | 0,0000048 |  |
| ***Qr*** *(SCMH)* | u2 | 0,2 | normal | 0,0252 |  | ***0,0252*** |  |
| Combined uncertainty E (SCMH) | u(E) |  |  |  |  | 0,028 | Expanded U (% |
| **Expanded uncertainty E (SCMH)** | **U(E)** |  |  |  |  | **0,056** | 0,18 % |

**Mathematical Model:**

***E [%] =*** ***[(Qm-Qr)/Qr]*100***
***u(E)=*** ***SQRT(u2(Qm)+u2(Qr))***
**U(E)=** **2*u(E)**

| Sensitivity Coefficients |  |  |  |  |  |
|---|---|---|---|---|---|
| **Flow rate (SCMH)** | **S(P)** | **S(T)** | **Repeatability** | **Reference std uncert** | Expanded U(%) |
| 37,5 | 0,037146893 | -0,133400654 | 0,0700 | 0,030375 | 0,41 |
| 31,1 | 0,030775543 | -0,109627674 | 0,0100 | 0,025191 | 0,18 |
| 24,4 | 0,024236635 | -0,085238062 | 0,0186 | 0,019764 | 0,23 |
| 16,2 | 0,016074979 | -0,055417462 | 0,0088 | 0,013122 | 0,2 |
| 13,3 | 0,013179277 | -0,045209954 | 0,0100 | 0,010773 | 0,23 |
| 9,3 | 0,009196684 | -0,031436282 | 0,0120 | 0,007533 | 0,31 |
| 6,6 | 0,00654682 | -0,022539557 | 0,02 | 0,005346 | 0,63 |

**Table 3.** Analysis of the uncertainty evaluation for a representative flow rate

In the uncertainty analysis presented above the following experimental aspects should be emphasized:

1. As mentioned in the experimental part of this report the calculation of the flow rate of the TS was based on the recording of the actual pulses of the meter with an oscilloscope. Due to limited memory space of the oscilloscope it was not always possible to record big enough number of pulses of the meter. This was true especially for the lowest flow rates. Therefore, these lowest flow rates have large uncertainties which are not representative for the operation of the reference facility as used under typical calibration conditions.
2. The memory space of the oscilloscope could be extended but this was not technically feasible within the time constraints posed by the project schedule. The purchase of the memory module would cause additional delay therefore the decision of the laboratory was to run the tests under expanded uncertainties.
3. The SIERRA Bell Prover facility is traceable to the national length standards of EIM and to NIST. The auxiliary equipment used is traceable to the national temperature and pressure standards of EIM.

## 6. References

[1] Sierra Series 101 Cal-Bench$^{TM}$ Automated Primary Calibration System, Instruction Manual, Part Number IM-101, 09/99 Revision F.
[2] Special Procedures, Quality Manual of Low Pressure Gas Flow Laboratory, Quality System ISO 17025, EIM.