# METROLOGICAL CHARACTERIZATION OF A CAPILLARY TYPE THERMAL MASS FLOWMETER (CTTMF) FOR NATURAL GAS METERING

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**INTRODUCTION:** *Nowadays, smart static gas measurement technologies are available on the market and are used for metering natural gas consumption of final consumers. Both ultrasonic and thermal-mass flow metering technologies are considered today as "new electronic gas meters". Such new digital meters require an adequate knowledge of the measurement principle in order to carry out correct calibration procedures. In other words, we are in the digital age of the gas measurement: digital meters require digital calibrations. The calibration procedures in use to calibrate a traditional (mechanical) "analogue" gas meter (such as a diaphragm meter or a rotary piston meter) are not fully adequate for the calibration of an electronic, digital meter.*

*Aim of this work: some technical features of calibration (such as the sampling during the measurement sequence) are presented and analyzed. A first series of calibration results of a sample of domestic, capillary type (by-pass), thermal mass flowmeters are provided and discussed in order to stress the metrological problems and solutions for a correct calibration procedure of this type of electronic gas meters.*

## Operating measurement principle of a CTTMF

*The new generation micro-thermal mass flow sensors (such as CMOS: Complementary Metal-Oxide Semiconductor, or MEMS: micro-thermal calorimeters) are based on the cooling of a heated miniaturized object (micro heater) placed in the flow. The measurement arrangement is composed of three basic elements (Figure 1): two temperature sensors and a central micro heater; both the temperature sensors and the micro heater are controlled by a suitable electronic module. Gas enters the meter and is divided into two flow paths; in both the laminar flow regime is ensured: in the bypass capillary tube the laminar flow regime is ensured by the very small diameter of the capillary, and in the main tube by the pressure dropper/laminar flow element.*

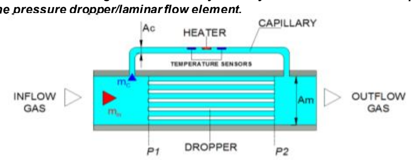



*Figure 1 - Basic elements of a by-pass capillary thermal mass flowmeter.*

*In the micro-thermal mass flow sensor, the temperature difference between two temperature sensors placed symmetrically upstream and downstream of the micro heater (see Figure 2) detects the passage of gas flow. If no gas is flowing over the sensor, the two thermo-elements measure the same rise in temperature (see Figure 2).*

*When the gas stream flows through the micro heater the temperature symmetry is disturbed, and the asymmetry can be expressed as a temperature difference between the two temperature sensors (see Figure 2). This temperature difference signal, which exists in the form of a voltage difference (thermopile), is processed in the analogue part of the sensor chip and then digitalized in the digital part. This measurement signal (voltage difference) is proportional to the mass flowrate of the gas flowed over the sensor-chip.*

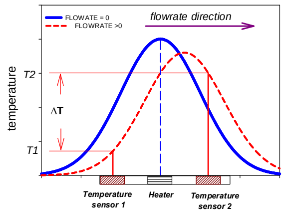



*Figure 2 - Temperature profiles in a CTTMF: with flow (dashed line) and without flow (continuous line).*

*Basically, the micro-thermal mass flow sensor uses the thermal properties of the gas to directly measure the mass flow rate (considering the electric power supply, $Q_{el}$, provided to the micro heater as being equal to the thermal power, $Q_{th}$, generated by the Joule's effect ($RI^2$) and lost to the gas flow by means of forced convective heat transfer (see ISO 14511:2001):* $Q_{el} = RI^2 = Q_{th} = m_c c_p \Delta T$ *The sensor chip detects the mass flow rate in the capillary tube ($m_c$): if the flow regime is laminar in both the circuits (the capillary one and the main one) the ratio $m_c/m_m$ (mass flow rate in the capillary circuit/mass flow rate in the main pipe) is constant (typically equal to the ratio between the cross section areas $A_c/A_m$). The sensor uses the basic principle that each gas molecule has the specific ability to pick up heat (forced convective heat transfer). This property, called the specific heat for a constant pressure (cp), directly relates to the mass and physical structure of the molecule and can be determined experimentally. The physical structure of molecules varies widely from gas to gas, as does the specific heat, cp, which varies depending on the gas composition and temperature (for a gas with a "real" behavior, not ideal gas). Changes in $c_p$ also imply changes in the thermal conductivity $\lambda$ of the gas, since the thermal diffusivity $\alpha$ of the gas is $\alpha = \lambda/(c_p \cdot \rho)$, where $\rho$ is the gas density.*

*The gas sensitivity (or gas identification/recognition) represents a crucial feature for the measurement reliability. Nowadays, the new and improved generations of CTTMF are able to sense gas composition, providing possible corrections to all current gas families (compliant to EN 437:2009).*

### Measurements Description

*A set of 5 CTTMF meters, G4 sized (full scale of 6 m³/h), have been tested at a national primary standards calibration facility, using the "BellGAS" primary volumetric standard (bell prover with capacity of 160L, see Table 1 and Figure 3). For each tested meter, the calibration has been carried out for 7 measurement points (representative flow rates: 1%-10%-20%-30%-50%-75%-100% of full scale); for each measurement point, 3 repetitions have been performed. The calibrations have been carried out in steady-state flow regime. The working fluid is air, at 3 fixed nominal temperatures: 18.0°, 21.0 °C and 24.0°C, while base pressure and temperature for volume conversion were P=101325 Pa and t=15 °C respectively. For each calibration test the volume and number of samples are reported in table 2.*

Table 1 -Test facility characteristic

| | | |
|---|---|---|
| Minimum flow rate | | 0,06 (m³/h) |
| Maximum flow rate | | 7,2 (m³/h) |
| Bell prover Volume | | (160 ± 0.17% )l |
| Volume resolution | | 0.01 l linear encoder and optical readers. |
| Volume relative uncertainty $u_V$ | Low flowrate | 0,15 (%) |
| | High flowrate | 0.12 (%) |

Table 2 – Volume and number of samples for each calibration test

| flowrate/ m³·h⁻¹ | volume passed through meter/l | # sampling |
|---|---|---|
| 0.06 | 19.758 | 2371 |
| 0.60 | 20.223 | 243 |
| 1.20 | 21.797 | 131 |
| 1.80 | 32.076 | 128 |
| 3.00 | 59.078 | 142 |
| 4.50 | 80.094 | 128 |
| 6.00 | 107.197 | 129 |

*Figure 3 – Experimental setup and test facility.*

### Measurement and Sampling

*In the electronic meters not directly connected to the electricity grid , in order to reduce battery consumption, the measurement can not be carried out continuously but it needs to be evaluated at fixed time intervals (sampling). The meters calibrated in this work acquire measurand (mass flowrate) every 0.4 second when calibration mode is set otherwise every 2 s. For each sample, the volume passed through the meter $V_{m,sample}$ is calculated multiplying the mass flowrate "m" passed through meter in the sample time, reciprocal density "$1/\rho$" and time sampling interval "$\Delta\tau$" : $V_{m,sample}=m/\rho \cdot \Delta\tau$*

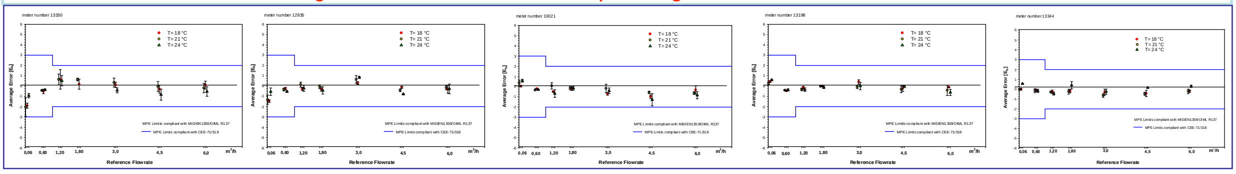
### Calibration results

*Figure 4 shows results of calibration test in terms of experimental standard deviation and mean percentages errors defined as:* $E = \sum_{i=1}^{3} \frac{e\%_i}{3}$ *with* $e\% = \frac{V_m - V_{ref}}{V_{ref}}$ *and*

*$V_m$ and $V_{ref}$ volume measured from meter under test and the reference meter respectively.*

*The calibration curves for all meters , as showed in Figure 4 , are full satisfactory with a good repeatability. All calibration points are within MPE limits and the values of the experimental standard deviation are always less than 0.45 for low flowrate ( $Q<Q_t$) and less than 0.3 for high flowrate except for a few calibration points. The exception in repeatability could be due to an inappropriate ratio between the gas volume passed trough the meter under test and the number of samples*

*Figure 4- Calibration Results : Mean percentage errors and standard deviation*




**CONCLUSIONS:**

*The smart static gas measurement technologies now available on the market require a novel calibration approach. The calibration procedures used to calibrate traditional (mechanical) "analogue" gas meters are not fully adequate for calibrating electronic, digital meters. The results show that some spurious data can occur. This limitation is presumably due to an incongruous ratio among flowrate test, volume test and number of samples. Future studies will be aimed to investigate the influence of sampling on error and measurement uncertainties.*