

PAPER • OPEN ACCESS

Experimental Assessment of Gas Static Meters Under Different Operating Conditions

To cite this article: Furio Cascetta *et al* 2021 *J. Phys.: Conf. Ser.* **1868** 012012

View the [article online](#) for updates and enhancements.



240th ECS Meeting ORLANDO, FL

Orange County Convention Center **Oct 10-14, 2021**

Abstract submission deadline extended: April 23rd

SUBMIT NOW

EXPERIMENTAL ASSESSMENT OF GAS STATIC METERS UNDER DIFFERENT OPERATING CONDITIONS

Furio Cascetta^a, Marcello Bondesan^b, Marilena Musto^c, Giuseppe Rotondo^c

^a University of Campania “Luigi Vanvitelli”, Italy (furio.cascetta@unicampania.it)

^b HERA Group Bologna, Italy (marcello.bondesan@inretedistribuzione.it)

^c University of Naples Federico II, Italy (marilena.musto@unina.it, giuseppe.rotondo@unina.it)

corresponding author*: marilena.musto@unina.it

Abstract. This paper compares the metrological performance of a sample of commercial domestic/residential smart meters for natural gas (G4). In particular, the performance degradation of electronic static and dynamic gas meters has been evaluated. The sample was composed by ultrasonic gas meters, thermal mass meters and diaphragm gas meters. The tests, performed on the gas meters, reproduce the most severe operating conditions (i.e. filed test) such as the influence of the gas composition, the temperature difference between gas and meter, the gas humidity and the presence of dust in the gas. Furthermore, the meters have been undergo to some endurance tests such as start and stop and to the high flowrate runs.

Keywords: smart gas meter, thermal mass meter, ultrasonic gas meter, diaphragm gas meter

1. Introduction

For residential use, the traditional end-user meters are based on a mechanical (dynamic) measurement principle (positive displacement technology), known as diaphragm gas meters. To promote an environmental responsibility of the residential customers and provide more services, the European Community has issued the Directive 2012/27/EU [1] introducing the concept of smart meter. The aim is to improve the invoicing process, i.e. providing to the costumers the fuel/energy time-consumption rate offering to consumers more billing transparency [2-4]. In practice, a smart meter performs four basic functions: (1) fiscal metering (2) measurement of gas consumption in real time, (3) transmission of the measurement data to the distributor, (4) correction of the gas volume at actual thermodynamic conditions (typically Temperature-correction). Smart Gas Meters can accomplish the above said main functionalities according two alternative designs: (i) by means of hybrid smart meters, i.e. traditional (mechanical/dynamic) diaphragm meters equipped by an electronic unit in order to integrate the measurement module with the data transmission and volume correction modules; (ii) by means of new-generation and electronic meters, based on static technologies. In particular, for residential metering two technologies are now available: the CTTMF (Capillary Type Thermal Mass Flowmeter) and the UGM (Ultrasonic Gas Meter). The first dry-type diaphragm gas meter was manufactured by Thomas Glover (1844). Cranic [5], in her short history of diaphragm meter, pointed out that the domestic gas meters manufactured today represent about 125 years of design evolution and that technological improvements in field of aluminum casting, powered metallurgy, plastic engineering and advances in several other engineering fields have all been incorporated in today's modern meters. Cascetta et al. [6] have investigated about diaphragm gas meter service lifetime. In particular, they suggested that the operative mean life for G4 diaphragm gas meter should be comprised between 11-16 years. Nilsson [7] has used in situ a fingerprint technique and provided an error analysis of a diaphragm



meter to deduce the error types that are likely to occur in such meters. Furthermore, Cascetta et al. [8] have studied the influence of standard on verification of in service G4 gas diaphragm meter. They have evaluated the degree of metrological agreement among different calibration results, introducing two alternative approaches about the metrological compatibility: quantitative and qualitative ones. The behavior of the smart gas meters, both dynamic (diaphragm gas meter) and static ones for residential metering, are quite unknown for residential application. Cascetta et al. [9] have studied the influence of calibrations method for the CTTMF. The results show that the leading parameter for these type of meters in calibration is the sampling time, in contrast of the delivered volume which is to be considered for the diaphragm gas meter. Gavra et al. [10] have presented two new residential smart gas meters: a mechanical gas meter and an ultrasonic gas meter fitted with communication module and integrated temperature conversion, obtaining benefits associated with introducing smart gas meters to the natural gas system.

The aim of our study is to evaluate the metrological behavior of 3 different types of new smart gas meters under different operating conditions such as the different gas composition, the difference of temperature between gas and meter, the gas humidity, the presence of dust in the gas, the presence of pressure fluctuations. Furthermore, the meters have been undergone to some endurance tests as start and stop and operation at maximum flow rate. After the tests, the meters were verified and the error curves were compared with the initial one.

2. Short survey about Gas Meter's technology

Nowadays, smart meters are mainly of two types, hybrid and fully digital. The hybrid ones, such as the diaphragm gas meter, have an analogical full mechanical sensor (first element) and an electronic unit (for thermo-compensation, data storage and data transmission). The fully digital meters have no moving parts and directly convert the flowrate into an electrical signal. For residential applications, the most used are the UMGs and CTTMFs. All the tested meters are G4, MID approved in the class 1.5%.

2.1. Positive Displacement Meter (PDM): diaphragm gas meter

Diaphragm gas meter (PDM), that is the most often used to measure the volume of natural gas, especially in the metering consumption by households, consists of four measurement chambers that work alternatively. A diaphragm meter can be compared to a two-piston double-action engine in which the diaphragms correspond to pistons and the meter chambers to the cylinders. Each stroke of the diaphragm displaces a fixed volume of gas and the diaphragms operate 90° out of phase so that, when one is fully stroked, the other is at mid-stroke. The slide valves, at the top of the meter, alternate the role of the chambers and synchronize the action of the diaphragms, as well as operating the crank mechanism for the meter register, when a demand for gas is made on the downstream side of the meter, a pressure drop is created across the meter and its diaphragms. This differential provides the force to drive the meter. The advantages and limitations of Positive Displacement (diaphragm type) gas Meters are reported in the Table 1.

2.2. Capillary Thermal Mass Gas Meter

The CTTMFs (Capillary Type Thermal Mass Flowmeters) are static meters based on a MEMS micro-thermal mass flowrate sensors equipped with CMOS technology. The sensor is composed of two temperature probes (Pt100), placed symmetrically upstream and downstream of the central micro-heater. The measurement principle is based on direct proportionality between temperature difference of gas across the heater and the gas mass flowrate. The temperature reached by the gas downstream the heater depends also to the gas composition, therefore a crucial feature for the measurement reliability is the gas recognition. The main advantage of the CTTMFs is that they directly provide in output the mass gas consumption, independently from inlet pressure and temperature of the gas. Furthermore, it can provide the accounted gas volume at the reference (or base) thermodynamic conditions. In the table 1, advantages and limitations for thermal mass gas meters are reported.

2.3. Ultrasonic Gas Meter

The Ultrasonic Gas Meter (UGM) measurement principle is based on the proportionality between the transitional time of an ultrasonic wave and the gas velocity i.e. the gas flowrate. The UGM is composed by piezoelectric transducers capable of both generating and receiving ultrasonic pulses. The transducers take turn producing and receiving ultrasonic pulses that travel with and against the flow of the gas. While one transducer is sending a pulse, the other transducer is acting as a receiver. The difference in time it takes for the pulse to reach the transducers is used to calculate the velocity of the gas. The Ultrasonic Gas Meters are generally very stable, but they suffer the presence of dirty gas that can obscure the sensors. In the Table 1, advantages and limitations for UGM are reported.

Table 1. Advantages and limitations of gas Meters.

		High standardization
PDM	ADVANTAGES	Favourable ratio costs/performances Limited energy consumption
	LIMITATIONS	wear, elasticity degradation of the rubber Limited sensitivity at very low flowrate
CTTMF	ADVANTAGES	Intrinsic thermo-compensated measurement unaffected by time service
	LIMITATIONS	Sensitive to thermal gas properties Require power source (battery)
UGM	ADVANTAGES	high sensitivity at low flowrate unaffected by time service
	LIMITATIONS	Sensitive to dirty gases Require power source (battery)

3. OPERATIVE CONDITIONS AND TEST BENCH FACILITY

To evaluate the performance degradation of the new smart gas meters under different operating conditions, a set of 15 meters, for each type of gas meter, have been considered. For each meters sample, a calibration test has been carried out in an accredited and traceable laboratory. A preliminary error curve (reference errors curve) has performed and the “average reference errors curve” has obtained as mean of the “reference errors curve” of each type of gas meter. In other words, for example, the mean of the errors (for any flowrate) of the 15 UGM gas meters become reference error curve. The tests performed are listed in Table 2.

3.1. Test bench facility

The test bench facility is equipped with a bell prover standard for the lowest flowrate (0.040 m³/h, minimum flowrate) and a master-slave bench for the other flowrate values. The fluids used to calibrate the MUT are air and other gases (compliant to EN 437:2009 [11]). The compressibility factor was computed by the AGA 8 method [12]. Table 3 shows the best measurement capability of the laboratory test facility for the volume flowrate delivered and gas types (air and other gases).

3.2. Reference calibration curve

For each MUT type considered, a sample of fifteen smart meters has tested. The reference calibration curve has performed for seven reference values of the flowrate and repeated for 5 times and in compliance to the specific standards: UNI EN 1359: 2006 (diaphragm meters) [13], UNI EN 14236 (ultrasonic gas meters) [14], UNI 11625:2016 (thermal mass flow meters) [15]. The calibration volume values used for the different flowrate are reported in the Table 4.

For each flow rate value, the percentage error is determined as:

$$e_{\%} = \frac{(V_{slave} - V_{master})}{V_{master}} 100 \quad (1)$$

where V_{master} is the gas volume measured by the master meter (reference value), corrected at thermodynamic conditions (p,T) of MUT and V_{slave} is the gas volume measured by the MUT. For the 5 repetitions (at any flowrate value) the average percentage error is calculated as:

$$\bar{e}_{\%,j} = \sum_{k=1}^5 e_{\%,k} \quad (2)$$

The percentage error values $\bar{e}_{\%,j}$ calculated for each flowrate provide the reference calibration curve of each meter. For each sample of fifteen gas meters, the average percentage errors ($\bar{E}_{\%,p}$, for each flow rate value) are calculated as:

$$\bar{E}_{\%,p} = \frac{1}{15} \sum_{j=1}^{15} e_{\%,j} \quad (3)$$

here subscripts j and p are the total number of the sample gas meters and the number of the four manufacturers, respectively.

The experimental standard deviations, $s_p(\bar{e}_{\%})$, of the average percentage error are determined as:

$$s_p(\bar{e}_{\%}) = \sqrt{\frac{1}{14} \sum_{j=1}^{15} (\bar{e}_{\%,j} - \bar{E}_{\%,p})^2} \quad (4)$$

The Figure 1 shows the average error curve (each point is the average of 75 measurement values). Each MUT shows the reference calibration curve within of the MPE (Maximum Permissible Errors) limits. All the points are high repeatability, in fact the standard deviation is, always, within the range 0.09 and 0.57.

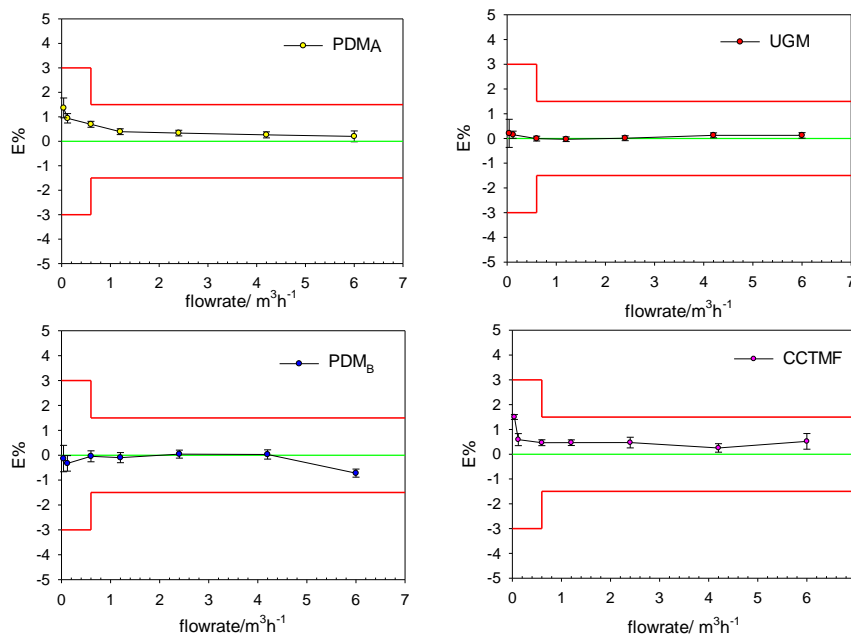


Figure 1. Average error curve for each gas meter sample type: mean percentage errors vs flowrate

Table 2. Test performed on the gas Meters.

installation conditions	aging tests
<i>different gas types</i>	<i>dirty gas</i>
<i>pressure fluctuations</i>	<i>extreme temperatures</i>
<i>influence of the humidity</i>	<i>start and stop and runs at maximum flow rate</i>

Table 3. Best measurement capability of the laboratory test facility for different flowrates.

Fluid	relative percent uncertainty (-)	flowrate (m ³ /h)
Air	0.29<U%<0.30	0.1Q _{max} ≤Q≤Q _{max}
	0.30<U%<0.35	Q _{min} ≤Q≤0.1Q _{max}
Other Gases	U%=0.33	0.1Q _{max} ≤Q≤Q _{max}
	0.33<U%<0.39	0.1Q _{max} ≤Q≤Q _{max}

Table 4. Calibration volume passed through MUT for the different flow rates.

Flow rate	m ³ /h	6.0	4.2	2.4	1.2	0.6	0.12	0.04
Volume	m ³	0.2	0.2	0.2	0.1	0.1	0.036	0.012

4. Tests procedure description

All tests simulate the field conditions and they are repeated 5 times, as for the initial error curve. The results are reported in terms of curves or tables. For the “installation condition” tests (no aging test), each test has been carried out on a single meter (one for each manufacturer/meter type); the results have been compared with the “initial error curve”. For the “aging tests”, each meter type has been undergo to all aging tests in sequence and, at the end, every cumulative error curves have been determined and compared with the “initial overall error curve”.

Test 1 - Natural gas methane mixtures with other gases-The influence of gas composition for the gas meters was considered in compliance with EN 14236:2007 [14]. The compressibility factor was computed by the AGA 8 method [12]. The test has carried out on the four type of meters, the error curves named Air are the reference errors curve (figure 2). The legend of figure 2 refers to the different gas composition in compliance with the EN 14236:2007 [14]. It is possible to note both the static meters suffer the variation of gas composition; this is mainly due to their measurement principle. In particular, different gas composition implies different specific thermal capacity: this influences mainly the gas temperature in the CTTMF due to the variation the thermal capacity, even if the CTTMF is equipped with an algorithm that allows the gas the recognition. About the UGM meter type, the spread of curves are mainly due to the different velocity of propagation of the ultrasonic waves across the different gases.

Test 2 - Different pressure fluctuations- This test evaluates the influence of the network pressure fluctuation on measurements performed by the MUTs. Three different flow rates were considered for two different fluctuation with frequency values (Table 5). This test is particularly significant in absence of gas flow through the MUT to assure no measure gas volumes due to only gas movement in the measurement chamber caused to the pressure fluctuations. In the Table 5, the influence of pressure fluctuation on measurement errors. For the CTTMF the errors slightly decrease as the frequency of pressure fluctuation increases, instead for UGM the error increases as pressure fluctuation increases.

Test 3 - Influence of the humidity- For the humidity test, air with 60% of humidity and 20 °C of temperature have used. One MUT (meter B) was placed in the climatic room at temperature of 10 °C, that is lower than dew point temperature (12 °C), while the two reference meters (A and C) were placed in the laboratory at 20 °C. Between meters B and C there is a warm up system that increases the gas temperature up to 20 °C. In the Table 6, thermodynamic properties of the air passing through the MUT are reported. Two different gas flow rates have considered: 0.6 m³/h and 6 m³/h. The test has been performed for ten hours and the amount of condensed water measured was equal to 0.00079 g for 0.6 m³/h and of 0.0079 g for 6 m³/h. The amount of condensed water measured was less than the resolution of MUTs, therefore the errors encountered during the verification phase were imputable just to the effect of moisture on the sensors. The results of the “humidity” test (Figure 3) point out both static meter are unaffected by presence of water moisture, both error curves are very close with the reference one.

Test 4 - Aging by dirty gas- In the aging test by dirty gas, four mixture dust contaminants of different size diameters were introduced in the gas flow. The tests were conducted in compliance with UNI-EN 14236:2007 [14]. During the tests, 0.005 kg of dust with different sizes up to 400 μm was injected into the gas flow.

Test 5 – Aging by extreme temperature- The meters were tested in compliance with EN 1359:2006 [13] for three different temperature values: $-25\text{ }^{\circ}\text{C}$, $20\text{ }^{\circ}\text{C}$ and $+55\text{ }^{\circ}\text{C}$ [14] and for three different flow rates: $6\text{ m}^3/\text{h}$, $2.4\text{ m}^3/\text{h}$ and $0.6\text{ m}^3/\text{h}$. The gas that passes through the reference meter is always at $20\text{ }^{\circ}\text{C}$; after each test, the volume measured by MUT was corrected at reference meter temperature.

Test 6 - Endurance test (start and stop test)-The performances of smart meters considered, i.e. CTTMF, UGM and PDM were compared after start and stop test. The start and stop test consists in six runs at $0.80 Q_{\text{max}}$ ($=4.8\text{ m}^3/\text{h}$) for 60 s spaced by 15 s of stop ($Q=0\text{ m}^3/\text{h}$). The figure 4 summarizes the comparison between error curves: initial and after aging tests. The UGM metrological performances seems has not influenced by aging tests.

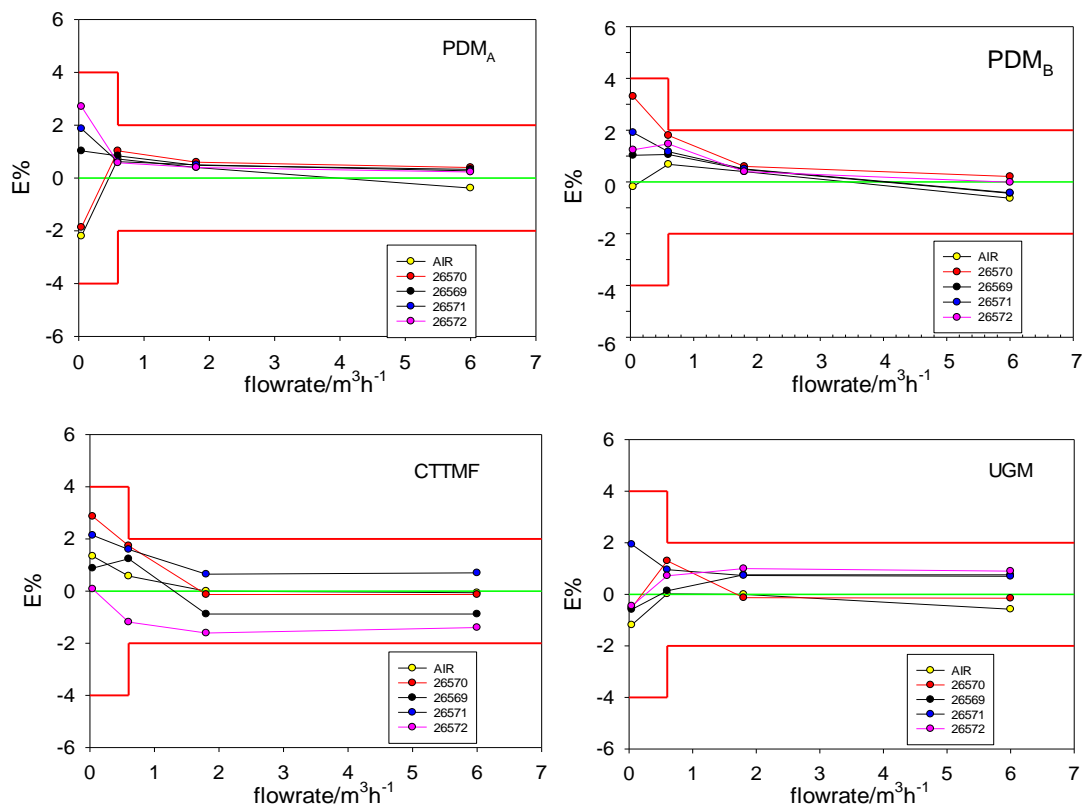


Figure 2. Average error curve for each gas meter sample composition.

Table 5. Measurement errors due to gas fluctuation.

Meter	Flowrate	Test Duration	Air temp.	Δp	Freq.	Error%	Freq.	Error%
Type	m^3/h	min	$^{\circ}\text{C}$	mbar	Hz	-	Hz	-
UGM	0	20	20.5	5	0.14	0	1.25	0
UGM	0.42	20	20.5	2	0.14	-1.76	1.25	1.60
UGM	2.25	20	20.75	2	0.14	-0.07	1.25	0.05
CTTMF	0	20	20.5	5	0.14	0	1.25	0
CTTMF	0.42	20	20.5	2	0.14	1.10	1.25	1.01
CTTMF	2.25	20	20.75	5	0.14	1.63	1.25	1.30

Table 6. Thermodynamic properties of the air.

	Temperature/°C	Humidity/%	Absolute humidity/(kg/kg)
A	20	60	0.00873
B	10	100	0.00763
C	20	50	0.00763

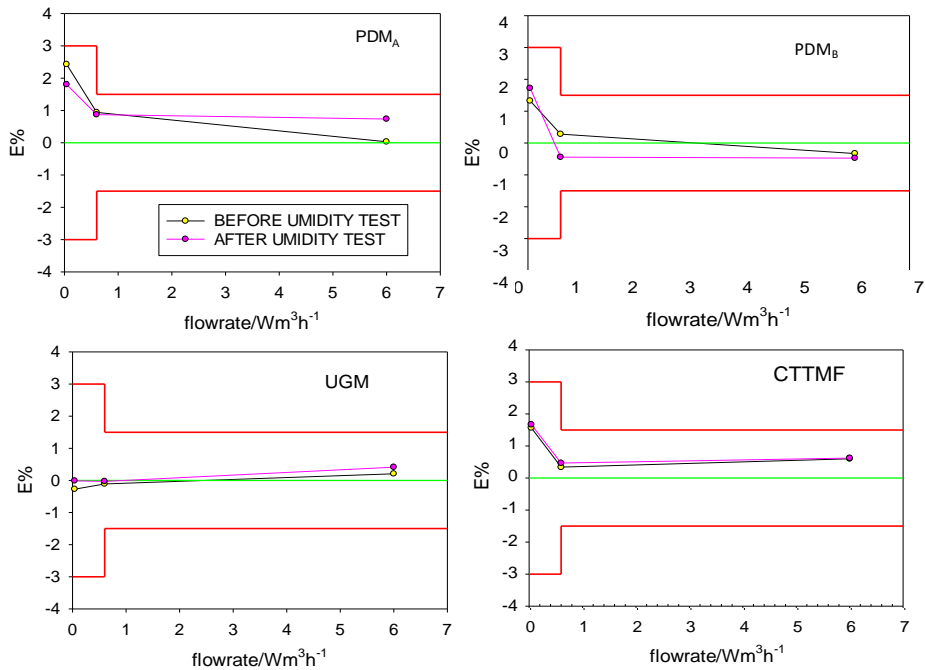


Figure 3. Humidity test results.

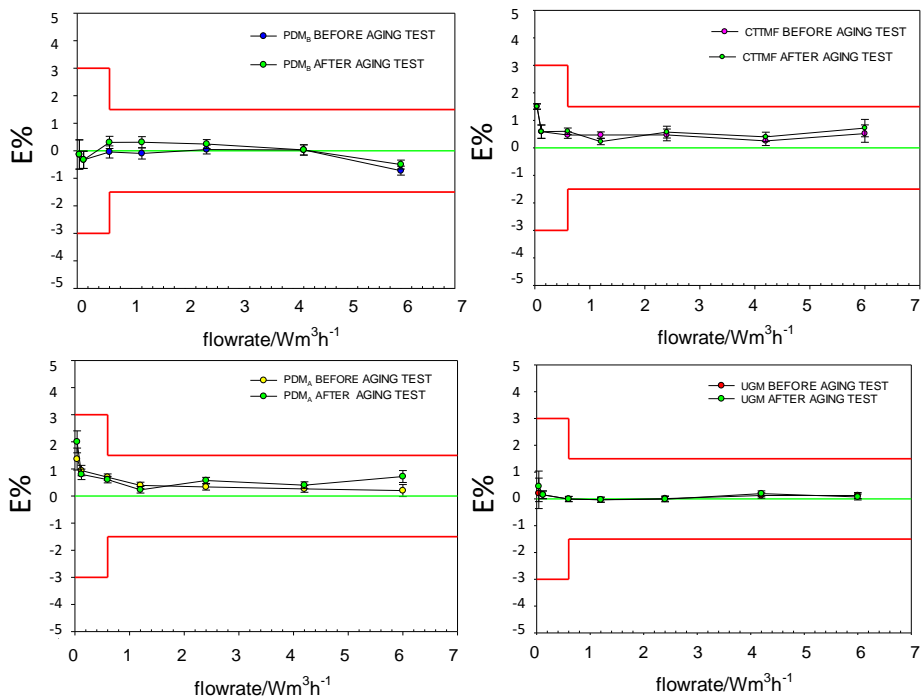


Figure 4. Comparison between error curves: initial and after aging tests.

5. RESULT AND CONCLUSION

The results provided in the paper have pointed out in the short period that the performances for the static and the dynamic gas meters are quite the same; the static meters have shown more flat error curve and high repeatability with respect to the static ones. Moreover, they have shown high sensitivity at very low flow rates. Furthermore, the static meters are unaffected by the wear (no performance degradation) with the advantage to be more performing with respect to the dynamic one in the long term. On the contrary, the measurement performed for both the static gas meters show they are affected by gas composition. In particular, the gas volume measured by CTTMF are high influenced by the gas composition and the error curves referred to different gas composition spread highly with respect to UGM one.

References

- [1] DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.
- [2] Okano H., Koyanagi A., “Strategy of the spread of automatic meter reading for 10 million customers”, 20th World Gas Conference, 1997.
- [3] Fasoli L., “A remote reading system for gas and water meters”, 23rd World Gas Conference, Amsterdam, 2006.
- [4] Huijzer E.L., “Infostroom-Automatic reading of the residential gas meter”, 23rd World Gas Conference, Amsterdam, 2006.
- [5] Cranic M.S., “A short history of diaphragm gas meter. Part II evolution of model diaphragm gas meter.”. Installation for Buildings and Ambiental Confort Conference XIX- Edition Timisoara – Romania 15 – 16 April 2010, pp 189-215.
- [6] Cascetta F., Rotondo G., “Assessment of domestic diaphragm gas meter service lifetime. OIML Bulletin vol LIII Number 3, July 2012 pp. 11-14.
- [7] Ulf RC Nilsson, Jerker Delsing, “In situ detection of inaccurate gas flow meters using a fingerprint technique”. Flow measurement instrumentation, vol. 9 issue 3, September 1998, pp. 143-152.
- [8] Cascetta F., Comazzi M., Musto M., Rotondo G., “An experimental intercomparison of gas meter calibrations”. Measurement 45 (2012) 1951–1959.
- [9] Cascetta F., Rotondo G., Piccato A., Spazzini P.G., “Calibration procedures and uncertainty analysis for a thermal mass gas flowmeter of a new generation”. Measurement: Journal of the International Measurement Confederation Volume 89, 1 July 2016, Pages 280-287.
- [10] Laurentiu Gavra, Petru Pupsa, Monica Sabina Crainic, Gheorghe Popa, “2012 10th International Symposium on Electronics and Telecommunications, ISETC 2012 - Conference Proceedings 2012, Article number 6408044, Pages 37-40.
- [11] WELMEC guide 11.1 (issue 3): Measuring Instruments Directive 2004/22/EC – Common Application for utility meters, May 2009. EN 437:2009, Test Gases – Test Pressures – Appliance Categories.
- [12] ISO 12213-2:2006, Natural gas – calculation of compression factor – Part 2: 680 Calculation using molar-composition analysis.
- [13] UNI EN1359:2006 Gas meters – Diaphragm meters.
- [14] UNI EN 14236:2007 – Ultrasonic gas meter.
- [15] UNI 11625:2016 – Thermal gas meter.