Analysis of domestic water meters field performance

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Introduction

As any other measuring device, water meters are not perfect instruments and when installed are not capable of registering the exact amount of water consumed by a user. Depending on its construction technology, each water meter has specific measuring limitations. This means that a portion of the water consumed may not be registered and therefore not billed to the customer. In such cases, the most frequent, the meter is said to have under-registration or a negative error. Other times, some meter technologies, under a particular set of circumstances, may lead to the opposite result, that is, to register more water than the volume actually consumed by the customer. Then, the meter is said to have over-registration or a positive error. In either case, as meter inaccuracies are recognised to be a critical component of apparent losses, it is important to quantify the magnitude of these measuring errors.

A crucial point to be considered is that the error of a water meter is not constant and independent of the flow rate. Typically, at low flow rates, errors are larger and more sensitive to external variables, while for medium and high flow rates error variations are smaller. Thus, the difference between the amount of water registered by installed meters and the actual volume consumed is a function of two parameters: a) the water consumption patterns of the users, defined by their consumption flow rates distribution, and b) the characteristic error curve of the meters. The weighted error of a meter, defined as the percentage difference between the actual consumption and the registered volume, can be obtained by combining these two parameters. Therefore, the parameter weighted error is a measure of the real field performance of a water meter when registering the water consumption of a given type of user.

The purpose of this paper is to determine both, the weighted error of new and worn domestic meters, in order to provide information on the real field performance that can be expected from meters installed in several water supplies in the Spanish East Coast. The work has been conducted between the ITA (Universitat Politecnica de Valencia) and FACSA, one of the major water supply companies in Spain.

With regards the initial error of new meters, a comprehensive study has been conducted for the last 5 years, in which numerous meter types have been tested to determine the initial meter performance. These tests were used in first instance to decide the most adequate meter to be installed in each water supply. Later, quality control tests were conducted to guarantee the performance of procured meters before they are installed.

This paper provides real values of the initial weighted error of several residential water meter models. Weighted error figures have been calculated for a consumption pattern extracted from a sample of domestic customers monitored in the water supply under study.

Secondly, an analysis of how the weighted error of a domestic meter changes over time has been conducted. For this purpose, a significant sample of this specific meter model, extracted from different water supplies, has been tested in the laboratory.

Finally, it should be mention that the main purpose of this analysis is to provide a reasonable order of magnitude of the deterioration rate of a domestic water meter in order to conduct a proper economic analysis to calculate the optimal replacement frequency of the meters (Arregui et al 2011). This deterioration rate can also be used to calculate the economic level of domestic water inaccuracies, which are a critical component of the economic level of apparent losses.

Testing of meters

Determining the error curves of new meters

In order to analyse the initial performance of new domestic meters, 11 commercial domestic meters were tested. In total, a sample of 330 meters, classified into 11 different types – 4 of which were oscillating piston meters and 7 of which were single-jet meters. A summary of the main metrological characteristics of the meters, including the version of the ISO standard according to which the meter model was approved, is shown in Table 1.

Table 1. Characteristics of the residential meters tested at ITA laboratory

Id	Number of meters tested	Technology*	Q1 (l/h)	Q2 (l/h)	Q3 (l/h)	Q4 (l/h)	Metrological Class	Standard
M1	30	SJ	30	120	1500	3000	B	ISO 4064:1993
M2	30	SJ	30	120	1500	3000	B	ISO 4064:1993
M3	30	SJ	30	120	1500	3000	B	ISO 4064:1993
M4	30	SJ	25	40	2500	3125	R100	ISO 4064:2005
M5	30	SJ	20	32	2500	3125	R125	ISO 4064:2005
M6	30	SJ	15	22.5	1500	3000	C	ISO 4064:1993
M7	30	SJ	12.5	20	2500	3125	R200	ISO 4064:2005
M8	30	OP	12.5	20	2500	3125	R200	ISO 4064:2005
M9	30	OP	15	22.5	1500	3000	C	ISO 4064:1993
M10	30	OP	7.9	12.7	2500	3125	R315	ISO 4064:2006
M11	30	OP	5.1	8.1	1600	2000	R315	ISO 4064:2005

*SJ = Single Jet ; OP = Oscillating Piston

Measuring errors of the meters were obtained by means a volumetric test bench using two calibrated probes of 10 litres and 200 litres. The bench is designed for testing meters ranging from 15 to 40 mm. For the particular case of domestic meters, the bench can fit series of up to 5 meters –which can be tested from 1 l/h up to 3125 l/h. Meters were tested taking readings with the meters at rest (standing start and stop test method). The 10-litres probe was used to test the meters for flows up to 120 l/h; while the 200-litres probe was used for flows - between 120 l/h and 3125 l/h. The scale division of the probes was of 0.01 and 0.2 litres respectively.

The determination of the error curve at low flow rates, where large variations occur, has been conducted with exceptional care so as to obtain a precise representation of the actual performance of the meters in the field (Barfuss 2011, Barfuss et al 2011, Richards et al. 2010). For this reason, selected meters have been tested at six flow rates lower than or equal to 120 l/h (Table 2).

Table 2. Average starting flow rate and error of indication for each meter type

	Qstart (l/h)	Test Flow (l/h)	6	10	15	30	60	120	600	1500	2500	3000
M1	8.8	Error (%)	-100	-36.51	-8.92	3.84	2.13	1.49	1.06	0.52	0.32	0.3
	Qstart (l/h)	Test Flow (l/h)	6	10	15	30	60	120	600	1500	2500	3000
M2	9.7	Error (%)	-100	-67.08	-17.49	-0.29	1.09	0.07	-0.33	-1.22	-1.38	-1.38
	Qstart (l/h)	Test Flow (l/h)	6	10	15	30	60	120	600	1500	2500	3000
M3	12.4	Error (%)	-100	-88.26	-23.87	2.47	2.39	0.77	-1.25	-0.50	0.13	0.3
	Qstart (l/h)	Test Flow (l/h)	6	10	15	25	60	120	600	1500	2500	3000
M4	8.6	Error (%)	-100	-34.60	-11.15	-1.05	-0.44	-0.80	0.23	0.55	0.73	0.76
	Qstart (l/h)	Test Flow (l/h)	6	10	20	60	120	600	1500	2500	3000	
M5	5.0	Error (%)	-39.89	-6.84	-0.93	-2.61	-0.58	0.39	0.42	0.35	0.20	
	Qstart (l/h)	Test Flow (l/h)	6	10	15	22.5	60	120	600	1500	2500	3000
M6	4.6	Error (%)	-38.55	-7.77	-1.90	-0.60	1.30	1.14	-0.62	-1.14	-1.50	-1.69
	Qstart (l/h)	Test Flow (l/h)	6	12.5	20	60	120	600	1500	2500	3000	
M7	4.0	Error (%)	-15.76	0.24	1.40	-1.34	0.27	0.91	0.61	0.31	0.08	
	Qstart (l/h)	Test Flow (l/h)	6	12.5	20	60	120	600	1500	2500	3000	
M8	1.5	Error (%)	-4.53	-1.41	-0.26	1.20	1.77	0.92	0.11	-0.55	-0.99	
	Qstart (l/h)	Test Flow (l/h)	6	10	15	22.5	60	120	600	1500	2500	3000
M9	1.8	Error (%)	-3.00	-1.48	-0.22	0.65	1.45	1.51	0.83	0.10	-0.34	-0.39
	Qstart (l/h)	Test Flow (l/h)	5	8	13	25	60	120	600	1500	2500	3000
M10	1.1	Error (%)	-2.32	-1.10	0.30	1.14	1.63	1.46	0.36	-0.53	-1.16	-1.29
	Qstart (l/h)	Test Flow (l/h)	5	8	15	30	60	120	600	1600	2000	
M11	1.6	Error (%)	-2.95	-1.01	0.39	1.21	1.62	1.47	0.75	-0.20	-0.53	

Determining the error curves of used meters

Additionally to the extensive analysis conducted for new domestic meters, a significant sample of one of the meter models tested was taken from the field. A total of 621 meters of meter model M1 (Table 2) having different ages were analysed. The average error of indication for different flow rates and ages is shown in table 3.

Table 3. Error of indication of meter model M1 classified by age

Age (years)	Meters tested	15 l/h	30 l/h	60 l/h	120 l/h	750 l/h	1500 l/h	2750 l/h
1	1	-98.5	-14.9	-4.7	-2.3	-2.2	-2.6	-2.4
2	1	-17.8	0.0	1.4	-0.9	-0.9	-0.8	-0.3
3	5	-66.7	-43.3	-25.6	-8.4	-3.0	-2.8	-1.5
4	3	-97.7	-40.7	-12.2	-4.2	-2.0	-1.4	-0.8
5	88	-36.9	-12.7	-7.6	-6.0	-4.6	-4.2	-3.1
6	10	-73.0	-20.0	-5.3	-3.1	-2.2	-1.8	-10.1
7	124	-53.1	-17.8	-8.3	-6.2	-3.9	-3.5	-5.7
8	161	-62.4	-21.3	-9.1	-5.6	-2.6	-2.2	-6.3
9	227	-55.1	-14.8	-5.6	-4.0	-2.3	-4.3	-7.9

The error curves of the meters were also calculated by classifying the meters according to their accumulated volume. The average error for each accumulated volume group is shown in table 4.

The errors of the meters clearly show that there is a tendency of the meters to under-register water consumption. However, a significant number of the meters, 30 out 621 showed an over-registration greater than 3% at medium-high flows. In an extreme case, the error of indication of one of the meters even reached +15%.

Also it has been observed that the strength of the magnetic coupling is not enough and there is some slipping between magnets at high flows.

Table 4. Error of indication of meter model M1 classified by accumulated volume

Acc. Volume (m^3)	Meters tested	15 l/h	30 l/h	60 l/h	120 l/h	750 l/h	1500 l/h	2750 l/h
0-500	139	-28.4	-9.2	-6.9	-5.8	-3.1	-2.7	-3.6
500-1000	122	-40.7	-9.1	-5.7	-4.5	-3.3	-2.1	-2.5
1000-1500	142	-54.0	-8.8	-2.7	-2.1	-1.5	-1.5	-1.6
1500-2000	78	-67.0	-17.3	-4.9	-4.3	-3.3	-7.3	-12.6
2000-2500	76	-78.8	-24.0	-7.5	-5.2	-3.0	-4.9	-9.7
2500-3000	24	-92.2	-55.0	-22.3	-6.8	-1.7	-1.0	-8.3
3000-3500	11	-93.5	-73.9	-25.9	-12.5	-3.7	-6.0	-30.3
3500-4000	13	-90.9	-52.3	-21.6	-15.1	-6.1	-4.2	-23.0
>4000	16	-99.2	-64.1	-31.5	-19.3	-13.6	-17.4	-35.3

Determining the consumption pattern

In order to calculate the weighted error of the meters, the specific customer's consumption pattern of the water supplies under study was obtained. During the research a total of 200 domestic users were monitored for a week. The methodology used for this study is the same as described in Arregui et al. 2006.

Table 5. Domestic customer's consumption pattern

Flow rates (l/h)	Consumption (%)
0-6	3.2
6-12	1.8
12-24	2.3
24-45	2.4
45-90	3.7
90-250	8.6
250-1000	72.7
1000-2000	4.5
2000-3000	0.8
>3000	0

Weighted error

Calculating the weighted error of new meters

The weighted error of new domestic meter models tested in this study was calculated using the software Woltmann (Arregui et al, 2009). This freeware version allows for the calculation of the weighted error of a meter by introducing its error curve and the consumption pattern.

Having an initial figure for the weighted error of the different meter options helps the water company in making the preliminary selection of the meters. However, it is important to mention that the best meter for the water company will not necessarily be the one with the lowest weighted error. The rate at which this error degrades with time is an essential component of any economic calculation and usually plays a critical role. Furthermore, there may be additional technical or financial reasons that may advise the acquisition of a different meter model. Table 6 summarises the weighted error calculation of all new meters tested. This table also shows the significant differences that can be found even for the same metrological class and meter technology.

Table 6. Weighted error of new domestic meters

Id	Technology*	Metrological Class	Weighted error (%)
M1	SJ	B	-3.45
M2	SJ	B	-5.41
M3	SJ	B	-6.37
M4	SJ	R100	-4.54
M5	SJ	R125	-3.32
M6	SJ	C	-3.5
M7	SJ	R200	-2.14
M8	OP	R200	-0.89
M9	OP	C	-1.02
M10	OP	R315	-1.04
M11	OP	R315	-0.76

*SJ = Single Jet ; OP = Oscillating Piston

Calculating the weighted error of used meters

A similar calculation has been conducted for all used meters taken from the field. Used meters, all belonging to the same meter model, were stratified according to their age or accumulated volume. Thus, it was possible to make an acceptable estimation about their degradation rate as a function of the time from installation (Figure 1) or the accumulated volume (Figure 2).

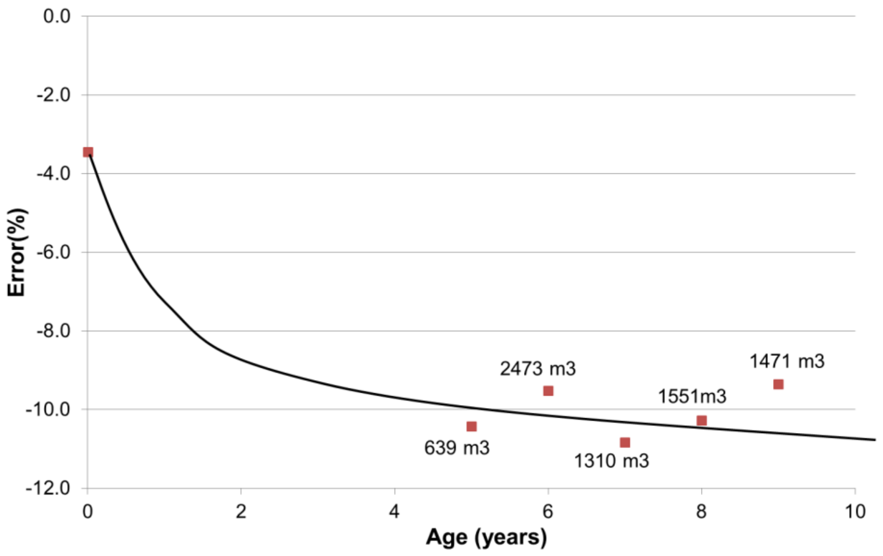

Figure 1 Degradation rate of the weighted error with age for a sample of domestic meters (Meter M1).

Typically, most studies consider that the weighted error of domestic meters degrade linearly from an initial value (Male et al 1985, Allender 1996, Yee 1999, Hill and Davis

2005, Arregui et al 2006, Mukheibir et al 2012). However, from the results presented in Figure 1 it is not obvious that a linear tendency adequately represents the way the error evolves with time. It seems that there is a fast initial degradation rate and afterwards the error tends to evolve at a much slower rate. The number of meter tested of each age is shown in table 3.

Also, when analysing figure 1, it should be noted that even though all meters belong to the same meter model (M1 in table 2), there have been significant manufacturing changes over time that may have caused important behaviour variances. At this time, more detailed information about these changes is not available.

Additionally, a figure representing the weighted error evolution with respect the accumulated volume can be plotted. In this case, when analysing the results, it should be kept in mind that most meters belong to age groups between 5 and 9 years.

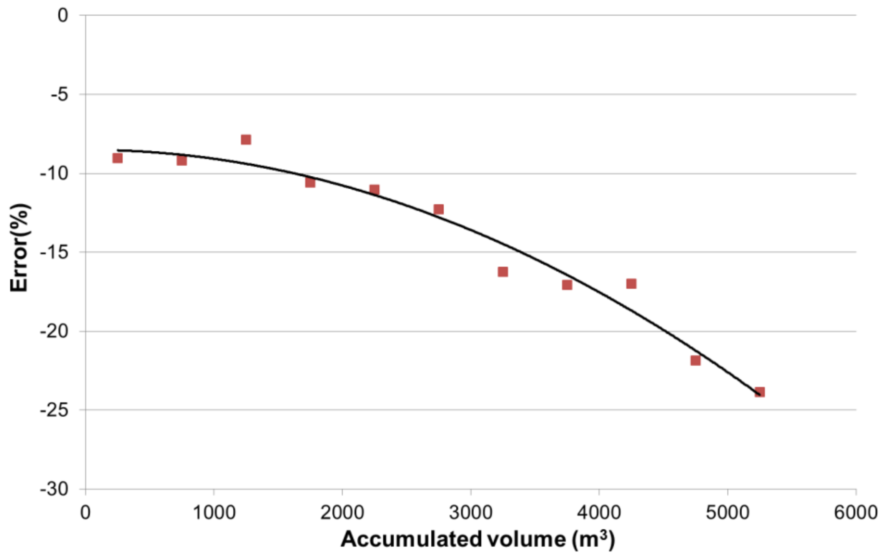

Figure 2 Degradation rate of the weighted error with accumulated volume for a sample of domestic meters (Meter M1).

Considering that the weighted error of most meters is close to -10%, figure 2 indicates that accumulated volume only has a significant influence when the register of the meter overpasses 2000-2500 m^3 of indication. Then, the weighted error seems to evolve in a quadratic manner.

Figure 3 shows the weighted error plotted against age and accumulated volume. This figure allows a better understanding on how both parameters affect the weighted error in particular case of the meters tested (meter model M1). As it can be seen in Figure 3, the dispersion of the error increases with the age of the meters. Meters being between 4 and 6 years old have the same weighted error (although it must be mentioned that there were no meters having an accumulated volume higher than 2000 m^3). Meters being 8-9 years old showed a great variability for the weighted error. Contrary to what happened for the youngest meters, this group had meters with a high accumulated volume, up to 6000 m^3.

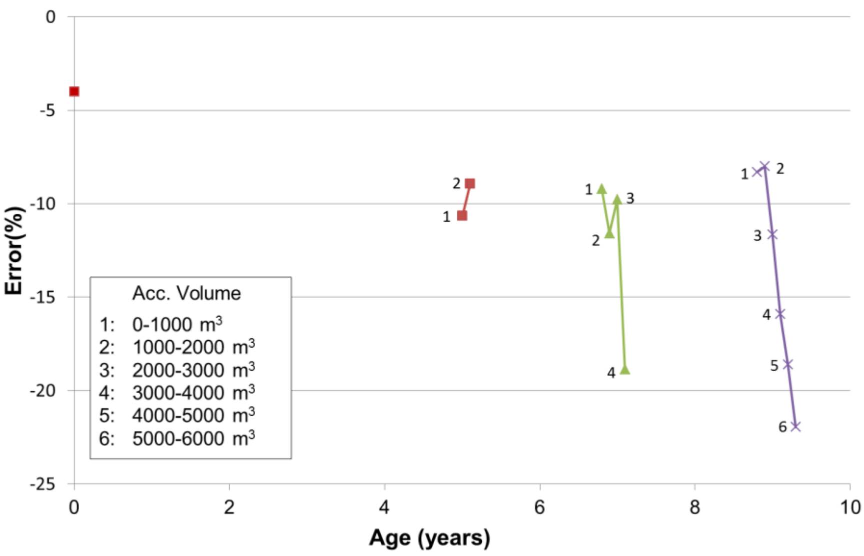

Figure 3 Degradation rate of the weighted error with age and accumulated volume for a sample of domestic meters (Meter M1).

A combined model can be built using the results from figure 1 and 2. To estimate the weighted error, this model takes into account not only the age but also the accumulated volume. It could be expressed in a form similar to:

$$\varepsilon_{weighted} = (A \cdot \ln(Age) + B) + (C \cdot Vol^2 + D \cdot Vol + E)$$

Obviously the coefficient needed in the equation should be determined for each water meter model and water supply.

Conclusions

This paper describes the results obtained from a work that has been conducted for the last two years in several water supplies in Spain.

The first part gives and order of magnitude of which can be the initial error of domestic meters when measuring a typical residential user. For the particular case study presented, the domestic consumption patter has been obtained in the field by monitoring a sample of customers. For the determination of the initial error curve of each meter model a sample of 30 meters (per model) has been tested at 10 flow rates.

The main conclusions obtained are the following:

- The weighted error of velocity meters (single jet) depends on the metrological class. Class B or its equivalent R100 shown an initial error ranging from -3.45% to -6.37%.
- For Class C or R125 or better the weighted error obtained was in a much narrower band, from -2.14% up to -3.5%
- Positive displacement meters showed a weighted error which was lower than velocity meters: from -0.76% up to -1.04%. The differences between models performance was small.

- There were two reasons why positive displacement meters showed better performance than single jet meters:
    - The shape of the error curve. At medium flows, where most consumption takes place, the error of positive displacement meters is always positive.
    - The starting flow rate value of positive displacement meters is always lower than single jet meters.

The second part summarizes the results of the performance analysis conducted over a significant sample of installed (used) meters. The main conclusions were:

- The average weighted error of most meters tested is close to -10%
- It seems that there is a fast initial degradation rate of the weighted error which later stabilizes with time.
- The degradation of the meter cannot only be modelled using the age of the meters. The actual degradation is best represented if both - age and accumulated volume – are considered.
- The accumulated volume seems to have no influence until it reaches 2500 m^3.
- A significant number of meters presented an important over registration at medium and high flows.

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