QUANTIFICATION OF METER ERRORS OF DOMESTIC USERS: A CASE STUDY

Arregui F.J.[1]; Pardo M.A.; Parra J.C.; Soriano J.*

farregui@ita.upv.es. Institute for water technology. Universidad Politecnica de Valencia.Valencia (Spain)

Keywords: Water meter performance; water meter accuracy; apparent losses

Introduction

Most residential water meters can be classified into two types: velocity meters (single jet and multiple jet) and positive displacement meters (oscillating piston and nutating disc). Positive displacement meters are insensitive to many of the influence factors that affect velocity meters. However water quality and suspended particles greatly degrade the water meter error curve and in some cases produce a definitive blockage of the meter.

In contrast, velocity meters are affected by many different factors like flow distortions, environmental and working conditions or changes in the internal dimensions of the measuring chamber or the inlet nozzle (for example those caused by calcium depositions) that may interfere with the flow velocity passing through the meter. The errors of velocity meters, especially for low flows, are sensitive to any increment of the drag torque on the sensor element. Consequently, many are the variables that can affect the accuracy of these meters. The combined action of these variables can have unpredictable consequences depending on the meter construction and materials. This circumstance makes it very difficult to predict in advance, for a given water supply, the behaviour of a specific type of velocity meter.

In Spain, the most used and less expensive metering technology for domestic users is single jet. Different manufacturers compete in this market offering models within a wide range of prices and metrological performances. The construction characteristics and quality diversity of available meters are considerable. Quite often, different models even from the same manufacturer are used simultaneously in the same water supply.

This scenario makes it more complex to analyse the real performance of the meters unless a long term strategy has been prepared for such a task. As said before, since many interrelated variables can simultaneously affect meters performance, a considerable sample has to be draw from the field. Therefore, only a long term study can provide with enough information to clearly identify and quantify the parameters with most influence on the error curve for each meter type.

This paper describes some of the problems that may arise when carrying out a research on this subject and illustrates it with examples of a real case study.

Methodology

The error of a water meter is not constant and independent of the circulating flow rate. Usually for low flows the errors are larger and more sensitive to external variables and at medium and high flows remain relatively stable through out the working life of the instrument. For that reason, the amount of water that a meter registers compared to the actual volume consumed is a function of two parameters: a) the water consumption patterns of the users which define their consumption flow rates and consequently the operation point of the meter and b) the characteristic error curves of the each meter type.

Combining appropriately these two parameters a weighted error (which is a measure of the metering efficiency of a water meter for a specific user) for a given type of meter and user can be obtained.

For domestic users, and because of the large number of meters that are installed in a utility to measure residential water consumption, this evaluation has to be carried out by statistical sampling of users consumption patterns and meters performances. The immediate consequence of this statistical approach is the uncertainty associated to each value obtained for both, the average consumption pattern of each type of user and the average error curve of each brand of meter. When combining these two uncertain parameters, the weighted errors that are calculated are only estimates of the real values which will remain unknown. Obviously, the quality of this latest estimate depends on the uncertainty associated to the previous parameters.

Uncertainties related to the water consumption patterns

The uncertainty associated to the estimation of the consumption patterns are caused by different factors like:

- *Erroneous stratification of the population*. As a first stage, and previous to the sampling step, a stratification of the population in several classes has to be carried out. The intention is to group the users in different classes of similar consumption characteristics, so the consumption flow rates in the group are as similar as possible.

  If this stratification is not properly done, a heterogeneous group, in which users may have very different characteristics, will be created. This will increase the variability of the consumption flow rates and therefore, for the same sample size, the uncertainty associated to the characteristic water consumption pattern of the class.

- *Incorrect selection of the sample.* In other cases, the criteria used to stratify the population can be correct. However, it is possible that some of the users selected for the sample may not really belong to the expected stratum. This is often caused by an improperly updated commercial database where some of the information stored about the users is inaccurate. In some other cases the user may have change its characteristics without the knowledge of the company (for example, it can have installed a different irrigation system or there may be more or less people living in the household).

- *Variability in the water consumption.* Water consumption in a household is different every day not only in quantity (Figure 1) but also in intensity (flow rate). For this reason, when determining the water consumption of a household, a minimum number of days should be considered so that the consumption registered is representative of the real water consumption. A minimum of a week or two of data-logging is advisable to reduce the uncertainty associated to this parameter.

- *Distortions caused by the measuring and data-logging equipment.* The information stored in the data logger about data consumption, does not exactly match to the actual values of the user water consumption. In first place, the meter is not capable of registering any consumption, whatever is its flow rate, and the error of the meter is not constant in all the measuring range. Furthermore, the pulse emitter resolution and the procedure used to store the information in the data-logger will also transform the flow signal that is finally processed (Arregui F. J., 1999).

When all data has been collected and processed a water consumption pattern - which gives information about how much water is consumed in each flow rate range - with its associated uncertainties is obtained. The problem when dealing with these uncertainties, in order to calculate the weighted accuracy of a meter, is to decide whether the volumes used in different flow rate ranges are independent of the volumes used in other ranges. For example, is frequent that the volumes used in the lower ranges are independent of the volumes used at higher flow rates because they only depend on the amount of leaks in the households and not on the intentional water used.

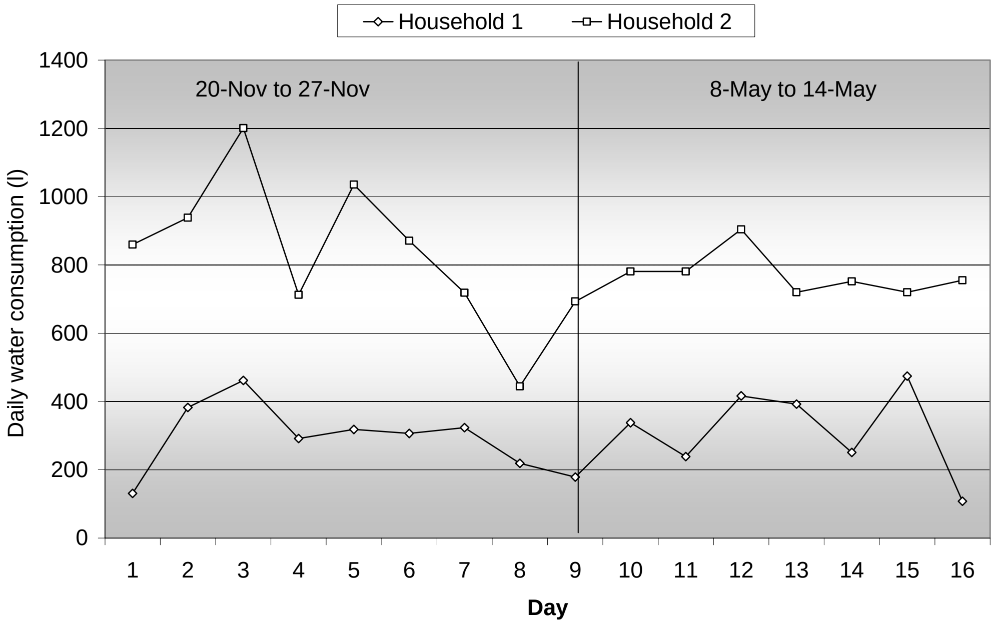

Figure 1. Total daily water consumption of two households for 16 days

Uncertainties related to the water meters error curve

To analyze the actual water meters performance several problems have to be faced. In first place, quite often water utilities simultaneously use a great variety of meters models, brands and technologies for measuring domestic consumption. This diversity leads to great difficulties when designing a proper approach to determine the amount of water not registered or registered in excess by the meters in the utility. The number of categories that have to be considered is too large and, consequently, the total sample to be drawn from installed meters to reduce the uncertainty of the results to an acceptable level is also too large to be economically feasible.

Furthermore, the tendency for most companies is to take a single snapshot of the meters errors, often during a single specific research project carried out in a relatively short period of time. An additional problem arises because usually a meter model is not produced for more than 2 or 3 years, or even less, without introducing significant changes in the design. Most of these modifications, although not externally perceptible, can alter the performance of the meter and the way its measuring error evolves with time. As a result it is almost impossible to predict how a meter model error will change with time, because there is not a well defined tendency. Different versions of the model will perform and degrade in dissimilar manners, even when they are under the same working conditions, and should be studied separately.

For this reason, a better approach for utilities to calculate in the medium-long term meters performance would be to make a continuous assessment of the error curve of installed meters. This way an appropriate quantity of meters of all ages (possibly versions) will be tested every year. With such approach a database of each version’s performance will be accessible and a significant amount of data will be available for the analysis.

In any case, it is important to keep in mind, once more, that the results obtained come from a statistical sampling of installed water meters and these results are uncertain. Knowing how to evaluate and reduce this uncertainty it is important to understand the results that will arise from the laboratory tests. Some of the uncertainties that can come up when estimating the error curve of the water meters are the following:

- *Erroneous stratification of the population.* The stratification of the meters is relatively easy if only variables like meter technology, brand, model and age are considered. However, the stratification is much more complex when trying to find other influence factors associated to the users or system characteristics. Examples of these parameters that may be of interest are the users facilities characteristics, the water consumption patterns of the users, the water quality, the number of pipe repairs in the network, weather conditions, etcetera. In such cases, the number of classes that should be created and sampled is so large that the study becomes unfeasible in the short term. Furthermore, as mentioned before, for a water meter model there may be changes through out the years in the manufacturing procedures and materials that can modify the influence of these variables on the metrological performance of the meter.
- *Incorrect testing procedure.* In first place the testing procedure can be wrongly defined. The selected flow rates, reference volumes, order in which the tests at different flow rates have to be carried out, or even the calibration of the test bench can have an important influence on the final results of the accuracy tests. In second place the tests can performed in an improper manner: faulty readings, meters that are left to dry for too long before they are tested, air remaining inside the system while the tests are done, etcetera. All these factors and circumstances can lead to confusing results which do not represent the real behaviour of the meters.
- *Unknown influence factors.* Some of the parameters may seem to have a random effect on the water meter accuracy and how it degrades with time. Since there are so many variables that affect the errors at the same time, the determination of the influence of a single variable may become a very difficult task. Besides, each user may have associated some specific variable (not identified) that can have a significant effect on the meter error curve. Examples are: a water softener upstream the meter, a particular pipe material, a leak, seasonal water consumption, etcetera.

The final result of this part of the work is an average error curve for each water meter stratum. In this case, the variables (errors of a given meter stratum for different flow rates) are not independent and the uncertainty of these variables has to be treated in a specific manner.

Calculating the weighted error

The weighted error is an indicator of the measuring efficiency of the water meters. It is calculated for each type of user and meter from the information of the water consumption pattern of the user and the error curve of the meter. It provides information about how much water it is not registered or registered in excess for a given meter and user type.

When analysing the results for the weighted error of a meter, the methodology used to “weight” both parameters is an important factor to be considered. Depending on the procedure followed to combine the water consumption patterns and the accuracy curve of the meters the weighted error will lead to different figures (Arregui et al. 2006).

Moreover, the interpretation of the weighted error should take into account the uncertainties related to the parameters used to calculate it. This way a final result of an estimated weighted error with an associated uncertainty can be given. It is always important to keep in mind that the weighted error of a meter is not a single figure (because of the way it is obtained) but an error interval in which, with a certain probability, the real error is expected to lay. This uncertainty has to be considered when planning future replacement scenarios to calculate the risks associated to the decisions taken.

It has been said before that this type of study has to be performed in a long-term basis. Therefore it is highly recommendable to have available a specific software package that can store and process both, water consumption patterns and water meter errors. This is the only way to guarantee that the calculations are always done in the same manner and are correct.

Case study

Following some results from a real case study will be analysed. During this work 200 households and more than 600 meters of different models and ages were tested.

Determination of the water consumption patterns

The water supply in which the study was carried out is a typical Spanish city, with most of its population living in apartment buildings. In order to determine the water consumption patterns (as the water meter perceives it) of domestic users four categories, depending on the type of hydraulic supply to the household and the water meter installation place, were defined:

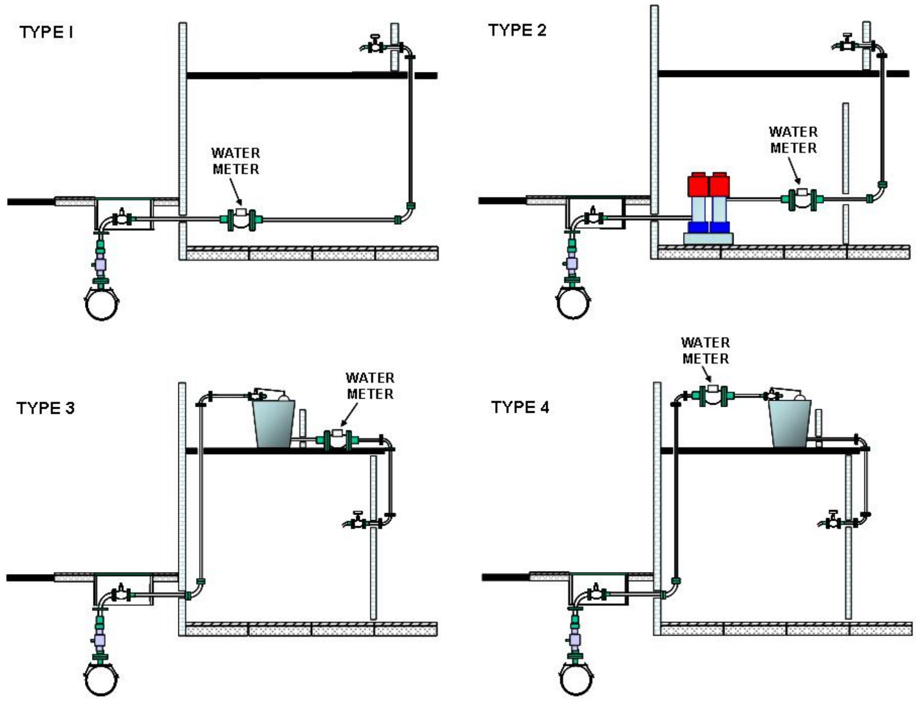

Figure 2. Categories of users considered during the study

1. Type 1. Direct connection to the water supply network. The water flows through the meter correspond exactly to the water demand inside the house. The consumption flow rates also depend on the network pressure.
2. Type 2. Water supply through a pump. The water flows through the meter correspond exactly to the water demand inside the house. The consumption flow rates are almost independent of the network pressure.

3. Type 3. Water supply through a reservoir with the water meter installed downstream this element. The water flows through the meter correspond exactly to the water demand inside the house. The consumption flow rates are independent of the network pressure.
4. Type 4. Water supply through a reservoir with the water meter installed upstream this element. The water flows through the meter depend on the inlet proportional valve and reservoir dimensions. The consumption flow rates depend on the network pressure.

Additionally, the influence that the amount of water that is consumed in a residence could have in the water consumption patterns was also examined. For that purpose, users with different monthly consumption volumes were chosen from each category.

Since the objective of this project was to obtain an initial approach to quantify domestic meters under registration no other variables that could influence water consumption patterns were examined at this stage.

A total of 200 users were monitored for at least a week to obtain the water consumption pattern. Class C oscillating piston water meters equipped with pulse emitters with a resolution of 0.1 litres were used. The users sampled for each category was calculated as a function of number of users in the water supply system. However, a minimum of 25 households for each category were monitored.

Difficulties found during the field work

Some users with the type 3 of configuration had installed pumps downstream the water meter to increase the pressure at the consumption points. In such cases the flow rates through the meter are conditioned by the pump operating point and do not correspond to the consumption flow rates of the user.

A number of the valves installed to control the refilling of the reservoirs were not proportional valves but shut-off valves. Therefore the filling of the reservoir was always produced at the same flow rate and the circulating flows through the meter for some type 4 households were not as expected.

Other users have a by-pass connection parallel to the reservoir. This way, when pressure in the network is sufficiently high, water is taken directly from the network. On the contrary, when pressure in the network is low the water is taken from the reservoir.

Conclusions

Users with configurations 1, 2 and 3 had similar consumption patterns. After a statistical analysis it was concluded that it could not be rejected the assumption that these consumption patterns belonged to the same group. The average consumption pattern of all households of this type (174 in total) with the associated confidence intervals for each flow rate range is shown in figure 3. The amplitude of the confidence intervals in the lower range is quite narrow. This means that the number of household monitored of these configurations is enough to have a good representation of their water used.

For users with configuration 4, for which the water meter is installed upstream the reservoir, the amount of water that is used in the lower ranges (less than 45 l/h) is significantly larger than for others configurations. The flow through the meter for this type of facility is in most cases restricted by the proportional valve that controls the refilling of the reservoir. Very often the highest flow detected is less than 500 l/h. The average consumption pattern for these households, including the associated confidence intervals for each flow rate range, is shown in figure 4. In this case, since the number of houses sampled is relatively small (26), the amplitude of the confidence intervals is much larger. This indicates that the number of houses that need to be monitored to obtain a reliable figure of the consumption pattern for this configuration, is considerable larger than 26.

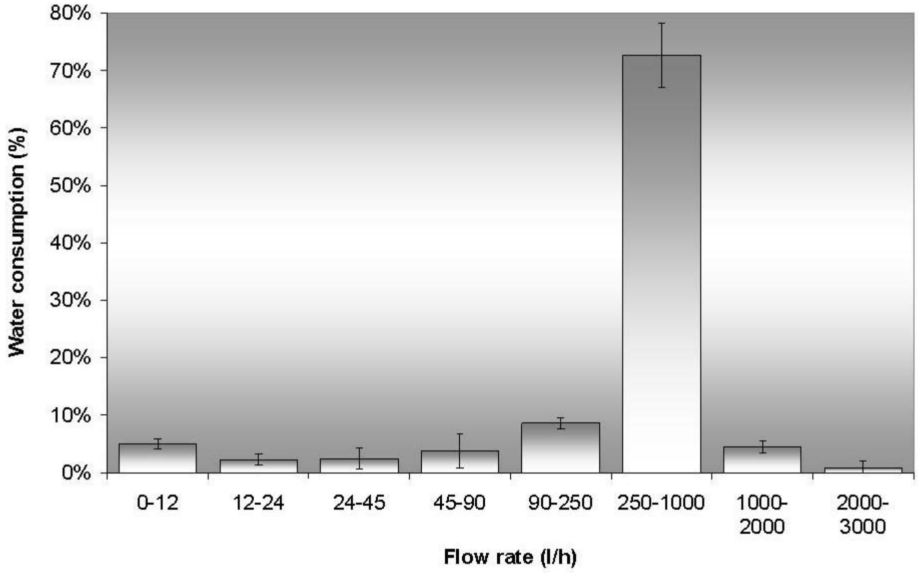

Figure 3. Water consumption pattern for meters which serve water directly to the user

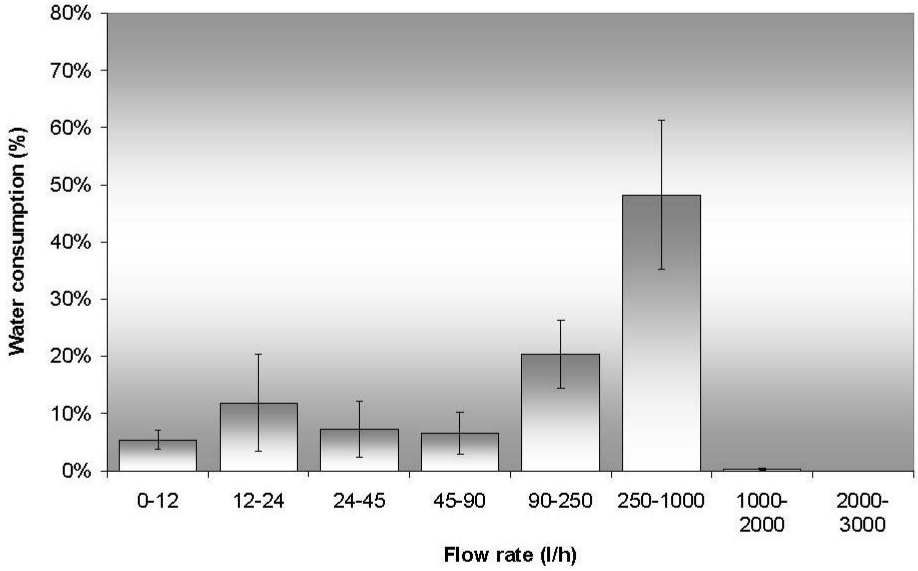

Figure 4. Water consumption pattern for meters which are installed upstream a reservoir

Finally when it was compared the average water consumption patterns of users with different monthly water demands it was found that there were not significant discrepancies as long as the water demand was not excessive.

Determination of the water meter accuracy curves

Approximately 75% of the meters installed in the water supply system under study belonged to two different models. Therefore the research project mainly focused in the analysis of these two models. A total of 160 meters of model 1 and 127 of model 2 were tested in the laboratory.

Meters of each model were also stratified into different age groups. The initial intention was to obtain a degradation rate for each model so the optimal replacement period could be calculated. However, due to the effect of unidentified variables a clear degradation rate could not be obtained, as shown in figures 5 and 6.

Prior to the laboratory work, the test procedure was carefully defined. Testing flow rates were selected so that the error curve could be reconstructed as accurately as possible from the resulting information from the tests. For this purpose meters were tested at six flow rates: 15 l/h, 30 l/h, 60 l/h, 120 l/h, 750 l/h and 1500 l/h.

Conclusions

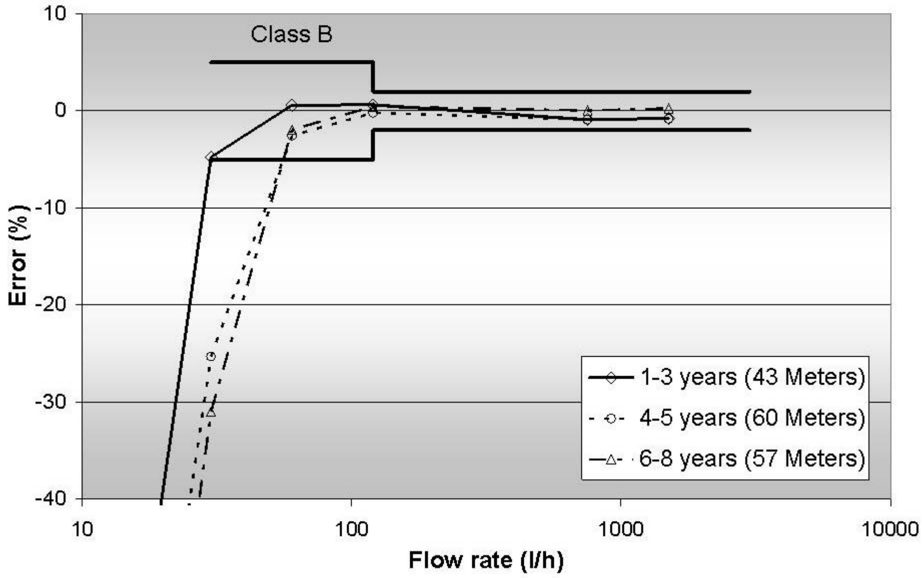

Figure 5. Accuracy tests results for two domestic Class B meters (Model 1)

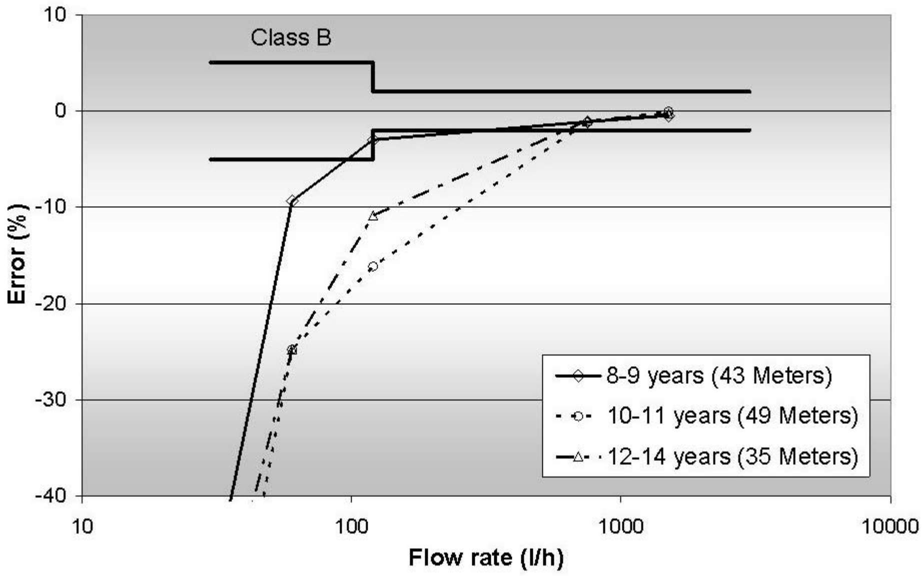

Figure 6. Accuracy tests results for two domestic Class B meters (Model 2)

As it can be seen, for model 1 (Figure 5), the average results of the error for meters 4-5 years old are quite similar to those obtained for meters 6-8 years old. The degradation of the meters seems to stop or at least slow down for the upper age ranges. A similar effect is detected for model 2 (Figure 6). The newer 10-11 years old meters show a similar accuracy curve compared to 12-14 years old meters.

For both meters the average error at 750 l/h and 1500 l/h remained inside the 2% error band. However, the behaviour at lower flows presented a much objectionable performance. Only 1-3 years old meters of model 1 were capable of maintaining its accuracy curve below the maximum permissible errors specify for a domestic Class B meter.

One of the factors that was identified as having great influence on the meters errors was the water quality. Calcium depositions inside the meter body, the turbine bearings and the entrance and exit nozzles caused severe damaged to the instruments, especially at low flows were the increase of drag has a significant effect on the error. However it could not be identified which variables (water quality parameters, brass composition, consumption flow rates, etc.) made the instruments more vulnerable from suffering calcium depositions.

In fact, model 1 presented two different degradation tendencies depending on how calcium depositions grew. During this study it was not possible to isolate the parameters that made depositions grow one way or the other.

Other common causes of meter failure were turbine breakage, uncoupling of the totalizer and the turbine at high flows, manufacturing defects that lead to inadequate low flow performance of new meters and a deficient repair of old water meters.

Another important result that should be mentioned is the high variability found for the error at low flows. In particular, only 5 meters of model 2 (from a total of 127) could measure water consumption at a flow of 15 l/h. The average error for these 5 meters was closer to -40% (Figure 7). At a flow of 30 l/h approximately 50% of the meters of model 2 were not able to register the flow. Even at 60 l/h there were 15% of the meters that could not measure any water consumption.

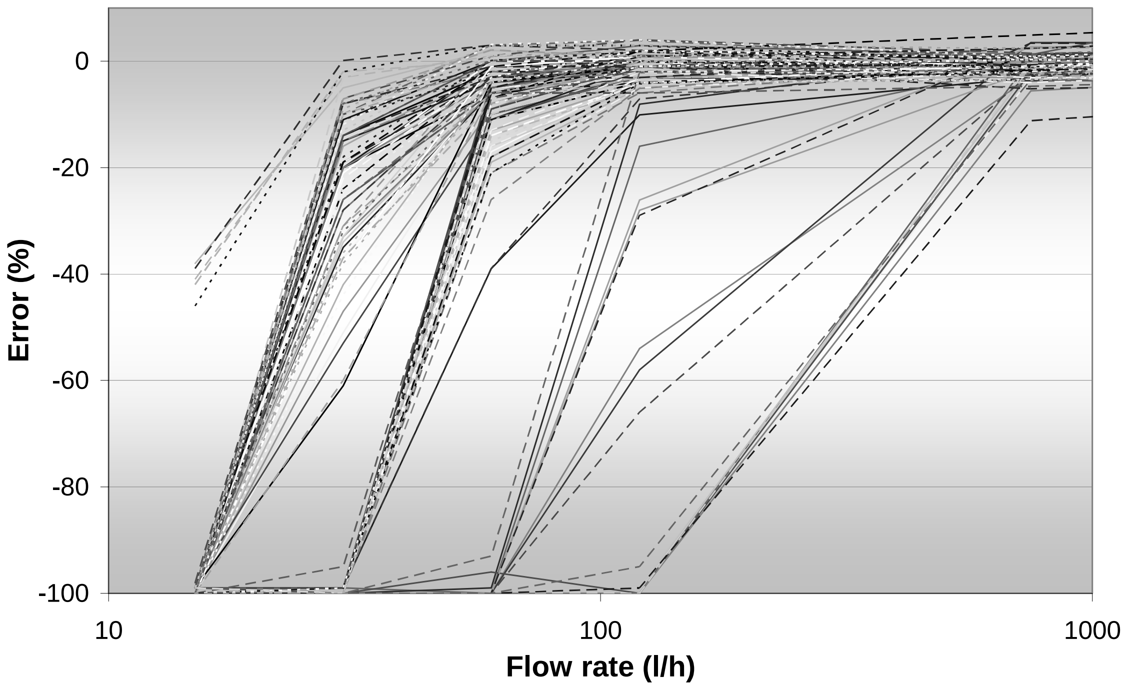

Figure 7. Accuracy tests variability of model 2 (160 meters)

Weighted error calculation

With the accuracy curve of the two models tested and the water consumption patterns of domestic users it is possible to calculate the weighted accuracy of the meters. For such purpose a specific software package was designed. This software is capable of storing all the information coming form the accuracy tests carried out at the laboratory and to manage all files containing the recorded water consumption of the users. In this manner it is possible to continue and update in the future the data collected during this project regarding the accuracy of the meters and the consumption flows of the users.

Furthermore, the availability of this software package, which incorporates a special modulus to calculate the weighted accuracy of the meters, makes it much easier, faster and reliable for managers the calculation of the metrological performance of meters which can be a quite complex task, especially when lots of data are collected.

Another important issue that should be mentioned when calculating the weighted accuracy is the importance of defining procedures. These procedures should be strictly followed when testing the meters and taking measurements of water consumption. If work is done following established procedures, collected data will have sufficient homogeneity to facilitate the analysis and to obtain more reliable results. Otherwise, the analysis of the data gathered during the study will be unfeasible.

The results obtained for weighted error of the two types of meters under study are shown in the following tables.

Model 1

Age	Meters which serve water directly to the user	Meters installed upstream a storage tank
1-3 years	-7%	-12%
4-5 years	-8%	-16%
6-8 years	-7%	-17%

Model 2

Age	Meters which serve water directly to the user	Meters installed upstream a storage tank
8-9 years	-11%	-23%
10-11 years	-13%	-28%
12-14 years	-12%	-26%

As it can be seen the final result for the weighted accuracy depends on many factors, each acting in a different direction, which lead to ambiguous results. Before the project started it was expected to find a degradation rate for the weighted accuracy of each meter model. Instead the value of the weighted accuracy found for different age groups of each model were quite similar.

For example, for model 2 the minor improvement of the error at medium flows (750 l/h) compensate the lost of accuracy at low flows in the 6-8 years old age group. This explains why meters 6-8 years old have a better weighted accuracy than meters 4-5 years old.

In both cases, the estimated errors of this single jet Class B meters when installed in a facility in which the flows through the meter are controlled by a proportional ball valve are very high. It is clear that under no circumstances these types of meters should be used in such facilities. Instead Class C single jet meters, oscillating piston meters or meters with a lower nominal flow rate (for example 0.6 m^3/h) should be installed.

Conclusions

Although serious field and laboratory work was carried out during this project at the end of the study it was clear that additional work was still needed in order to improve results reliability and to quantify the influence on the meters accuracy of different parameters. The complexity of this quantification comes from the fact that many variables are interrelated and affect meters accuracy simultaneously. Therefore, the amount of data required to identify the real influence of these variables is much larger than the information gathered during this project. For this reason, it was obvious that for this specific purpose, the study had to be extended on time.

However, to do so, well define procedures need to be implemented. Only with this approach it will be possible to store enough data in an adequately structured data-base and to analyse it in a simple and reliable manner. A common pitfall of many water utilities that initiate this type of studies has to do with the storage of the data collected, which is not saved in properly design data-bases that can support the insertion of new tests results and measurements of water consumption. For this reason it becomes very difficult to include in the original data set the additional work that can be done. Much information about how things are done or the procedures that were originally followed is usually lost.

In this sense, one of the most important conclusions that can be drawn from the project is the need of a specific software package that could manage and analyse all the information that can be collected in a long-term period. Such a tool assures that things are always done in the same manner and important information is kept saved and understandable.

Independently of the fact that the quantification of the influence of several parameters could not be obtained in this initial study, a reliable estimation of meters accuracy, and therefore commercial losses caused by meters inaccuracies, was calculated.

Additionally to meters accuracy, very interesting conclusions about meters performance and degradation were reached. In first place it was identify that water quality was an important factor in meters accuracy degradation. However, it was proved that this parameter does not affect all meters in the same manner since it interacts with other unidentified factors to produce dissimilar results. A prove of this was that even a specific water meter model, depending on where it was installed in the water distribution system, presented various degradation states. Water composition did not seem to be the cause for this result since some of the meters were installed in locations close to each other.

Another parameter that plays a major role in the accuracy rate of decay is the mechanical robustness of meters and its moving parts. It was found that a significant number of meters failures and meter under-registration were caused by the breakage of the turbine and the wear of the turbine bearings and the gears inside the totalizer.

References

Arregui F., Cabrera E Jr., Cobacho R. (2006). Integrated water meter management. IWA Publishing.
Arregui F.J. (1999). Propuesta de una metodología para el analisis y gestión del parque de contadores en un abastecimiento. PhD Thesis. Universidad Politecnica de Valencia. Spain.
Bowen P.T., Harp J.F., Hendricks J.E. and Shoeleh M. (1991). Evaluating residential meter performance. American Water Works Association Research Foundation . *Denver, CO*. USA.

Authors would like to thank the essential support of SPANISH MINISTRY OF EDUCATION, through the research project “Ordenación y valoración de estrategias orientadas ala progresiva eliminación de los depósitos de almacenamiento de los usuarios en los abastecimientos de agua urbanos”. CGL2005-03666/HID.