MATEC Web of Conferences **94**, 04002 (2017) DOI: 10.1051/matecconf/20179404002
CoSME'16

Statistical analysis of the measurement errors in an installation of water meters. Study on the volume of the water loss in the installation

Mihaela Rodica Clinciu[1,*], and *Ramona* Clinciu[1]

[1]Transilvania University of Brașov, Department of Manufacturing Engineering, Mihai Viteazu No. 5, Brașov, Romania

Abstract. The paper presents the estimation of the statistical parameters for experimental data collected in an installation consisting of several water meters and also a study on the volume of the water loss in the installation, aiming to emphasize ways in which errors in metering the consumed water are produced. The water meters analysed are of three types, belonging to two different precision classes. Data analysis was performed on data collected from the water meters considered, data representing the measurement errors.

1 Introduction

Estimation theory is a branch of statistic and signal processing that deals with estimating the values of parameters based on measured/empirical data. The parameters describe an underlying physical setting in such a way that the value of the parameters affects the distribution of the measured data. An estimator attempts to approximate the unknown parameters using the measurements [1, 2].

The paper presents the estimation of the statistical parameters for experimental data collected in an installation of water meters and a study on the volume of the water loss in the installation. The water meters considered in the present research are of three types, belonging to two different precision classes, connected in series arrangement [3].

2 Statistical analysis of experimental data

General metrology uses frequently the normal distribution as a statistical model, although usually in many situations asymmetrical statistical distributions, of Weibull type, occure [4]. In these cases one must verify the hypothesis that the data analyzed really comes from a normal population. Determining the appropriate statistical model is realized by verifying that the empirical distribution is consistent with the theoretical distribution assumed properly in the case studied.

The algorithm that performs the statistical processing of the experimental data involves the following steps:

* Corresponding author: clinciumr@unitbv.ro

1. The experimental data collection.

In the experimental research, there were considered three types of water meters belonging to two different precision classes. The considered water meters were used to measure a constant volume of water (10 liters).

The experimental installation (Figure 1) contains water meters of three types, connected in series arrangement: three water meters of type I (precision class B), three water meters of type II (precision class B) and three water meters of type III (precision class C). As to the precision classes of the water meters, class C represents high precision and class B represents mediate precision. Water meters of precision class C are in general branching water meters, while water meters of precision class B are apartment water meters, with a more accesible price, but with a lower precision [3].

Water meters of type I are apartment water meters for cold water or hot water, of precision class B, with nominal diameter Dn15 and minimum starting flow 30 l/h.

Water meters of type II are apartment water meters for cold water, of precision class B, with nominal diameter Dn15 and minimum starting flow 30 l/h.

Water meters of type III are single-jet water meters, of precision class C, with nominal diameter Dn15 and minimum starting flow 15l/h.

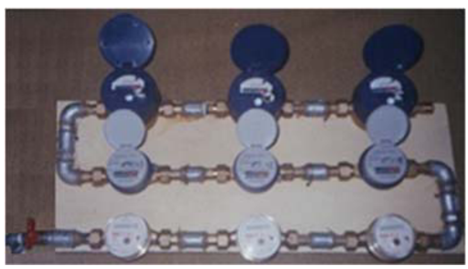


Fig. 1. Experimental installation.

The experimental data is represented by the measurement errors resulting by measuring a constant volume of water (10 liters), using the water meters considered. The operation was performed in laboratory conditions, by a single person, for n times. Experimental data is grouped into samples of a certain volume, n=18, for each water meter considered.

The maximum admisible errors of water meters are included in the Legal Metrology Norm NML 003-05 "Water Meters" [5], where it is specified that measurement errors on volumes delivered at flowrates between the transitional flowrate (included) and the overload flowrate may not exceed errors ± 2% for water having a temperature of ≤30 ºC.

2. Verification of the homogeneity of the samples of experimental data. During this stage, one must perform:

- the verification of the random feature of selection, using the method of iterrations;
- the removment of aberrant values, using the Grubbs general test.

3. The graphical representation of experimental data and the assumption of a theoretical distribution. This stage includes the construction of the probability plot and then, on its basis, the assumption of a statistical model presumed to be adequate for describing the experimental data.

4. Estimation of the parameters of the statistical model selected for each sample.

During this stage, according to the distribution considered, one must apply an analytical method of estimation (least squares, maximum likelihood) in order to determine the parameters of the selected model for each sample.

5. Validation of the statistical model. This stage consists in applying a goodness of fit test to all samples representing the experimental data. The goodness of fit test used are: the

general Kolmogorov-Smirnov test and the normality goodness of fit test Lilliefors. Distribution functions validated at a risk level $\alpha = 0.05$ are considered acceptable.

3 Case studies – water meters of precision classes B and C

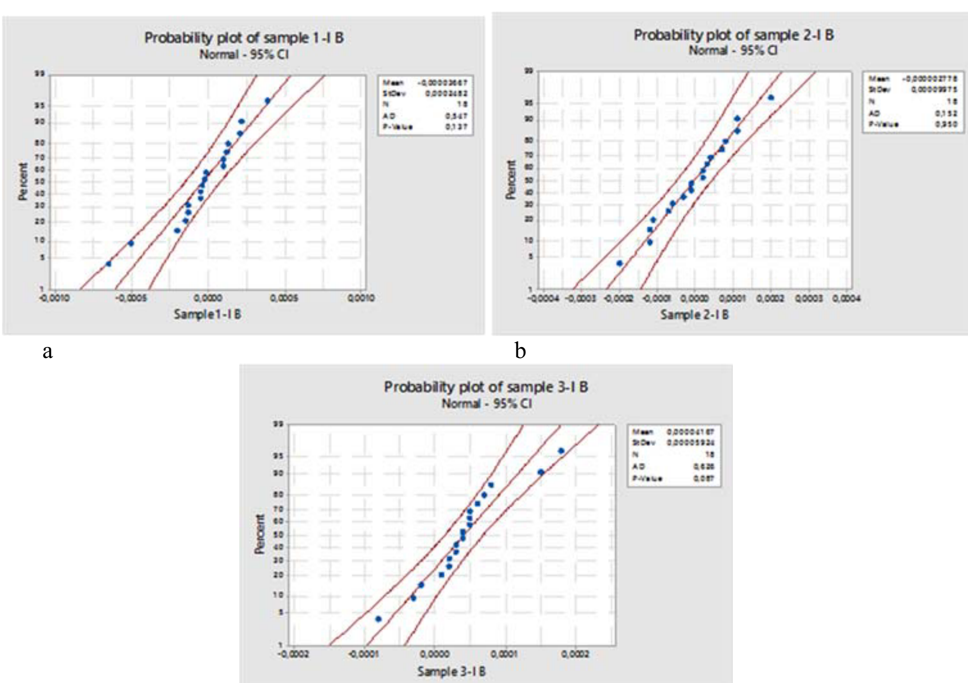
3.1 Water meters of type I, precision class B

The experimental data was collected by reading the indications of the water meters of type I, precision class B. It represents the measurement errors obtained by measuring a constant volume of water (10 liters) using the water meters considered.

The measurement errors of the water meters of type I, precision class B are shown in Table 1; on the basis of the probability plots presented in Figure 2, a, b and c, normal distribution is assumed for the samples considered. Table 2 presents the estimated values of the parameters of the normal distribution.

Table 1. Measurement errors of water meters of type I, precision class B.

Water meter	**Measurement errors** (m^3)
1- I B	-0.00004, -0.00013, 0.00012, 0.00013, 0.00021, 0.0001, 0.00022, -0.0002, -0.00013, -0.0007, -0.00005, 0.00039, -0.00005, -0.00015, 0.0001, -0.0005, -0.00002, -0.00001
2 -I B	0.00007, 0.00011, -0.00006, -0.0002, -0.00011, 0.00004, 0.0002, 0.00008, -0.00001, 0.00011, -0.00012, 0.00002, -0.00007, -0.00012,-0.00003, -0.00001, 0.00003, 0.00002
3 -I B	-0.00008, 0.00005, 0.00006, 0.00008, 0.00003, 0.00018, 0.00007, 0.00003, 0.00004, 0.00002, 0.00004, -0.00003, 0.00002, 0.00015, -0.00002, 0.00005, 0.00001, 0.00005



a b c

Fig. 2. Probability plots of the samples 1, 2, 3 collected by using water meters of type I, precision class B.

Table 3 presents the values of the statistics of the goodness of fit tests applied [3]. These values are compared to the critical values of the statistics of the goodness of fit tests, $d_{n,\alpha}$ for the Kolmogorov-Smirnov goodness of fit test and $L_{n,\alpha}$ for the Lilliefors goodness of fit test.

Table 2. Parameter estimation - water meters of type I, precision class B.

Water meter	1-I B	2-I B	3-I B
Mean	$m_1 = 0.00004$	$m_2 = 0.0$	$m_3 = 0.00004$
Standard deviation	$\sigma_1 = 0.00025$	$\sigma_2 = 0.0001$	$\sigma_3 = 0.00006$

Table 3. Validation of the statistical model - water meters of type I, precision class B.

Kolmogorov-Smirnov test: for $d_j \leq d_{n,\alpha} = 0.309 \Rightarrow$ the hypothesis of normal distribution is accepted		
$d_1 = 0.1661$	$d_2 = 0.0903$	$d_3 = 0.1663$
Lilliefors test: for $L_j \leq L_{n,\alpha} = 0.200 \Rightarrow$ the hypothesis of normal distribution is accepted		
$L_1 = 0.1105$	$L_2 = 0.0810$	$L_3 = 0.1663$

3.2 Water meters of type II, precision class B

The experimental data represents the measurement errors shown in Table 4, resulting by measuring a constant volume of water (10 liters) using the water meters of type II, precision class B.. The appropriate probability plots are presented in Figure 3, a to c, and normal distribution is assumed for each sample. Table 5 presents the estimated values of the parameters of the normal distribution and Table 6 presents the values of the statistics of the goodness of fit tests applied, which are compared to the critical values of the statistics of the goodness of fit tests, $d_{n,\alpha}$ and $L_{n,\alpha}$ [3].

Table 4. Measurement errors of water meters of type II, precision class B.

Water meter	**Measurement errors** (m^3)
1-II B	0.0005, 0.00014, 0.00023, 0.00022, 0.00012, 0.00016, 0.00012, 0.00011, 0.00023, 0.00004, 0.00022, 0 0.00006, 0.00002, 0.00028, 0.00017, 0.00005, 0.00007
2-II B	-0.00008, 0, -0.00003, 0, 0.00005, 0.00001, -0.00002, -0.0003, 0, -0.00002, -0.00006, -0.00009, -0.00005, -0.00005, -0.00003, -0.00007, -0.00011, -0.00001
3-II B	-0.0001, -0.00008, 0, 0.00002, -0.00005, 0.00004, 0, -0.00002, -0.00002, 0.00001, -0.00002, -0.00001, 0.00001, -0.00006, -0.00003, 0.00001, -0.00002, -0.00001

Table 5. Parameter estimation - water meters of type II, precision class B.

Water meter	1-II B	2-II B	3-II B
Mean	$m_1 = 0.00014$	$m_2 = -0.00004$	$m_3 = 0.00002$
Standard deviation	$\sigma_1 = 0.00010$	$\sigma_2 = 0.00005$	$\sigma_3 = 0.00003$

Table 6. Validation of the statistical model - water meters of type II, precision class B.

Kolmogorov-Smirnov test: for $d_j \leq d_{n,\alpha} = 0.309 \Rightarrow$ the hypothesis of normal distribution is accepted		
$d_1 = 0.1461$	$d_2 = 0.1743$	$d_3 = 0.2035$
Lilliefors test: for $L_j \leq L_{n,\alpha} = 0.200 \Rightarrow$ the hypothesis of normal distribution is accepted		
$L_1 = 0.1461$	$L_2 = 0.1634$	$L_3 = 0.148$

 DOI: 10.1051/matecconf/20179404002

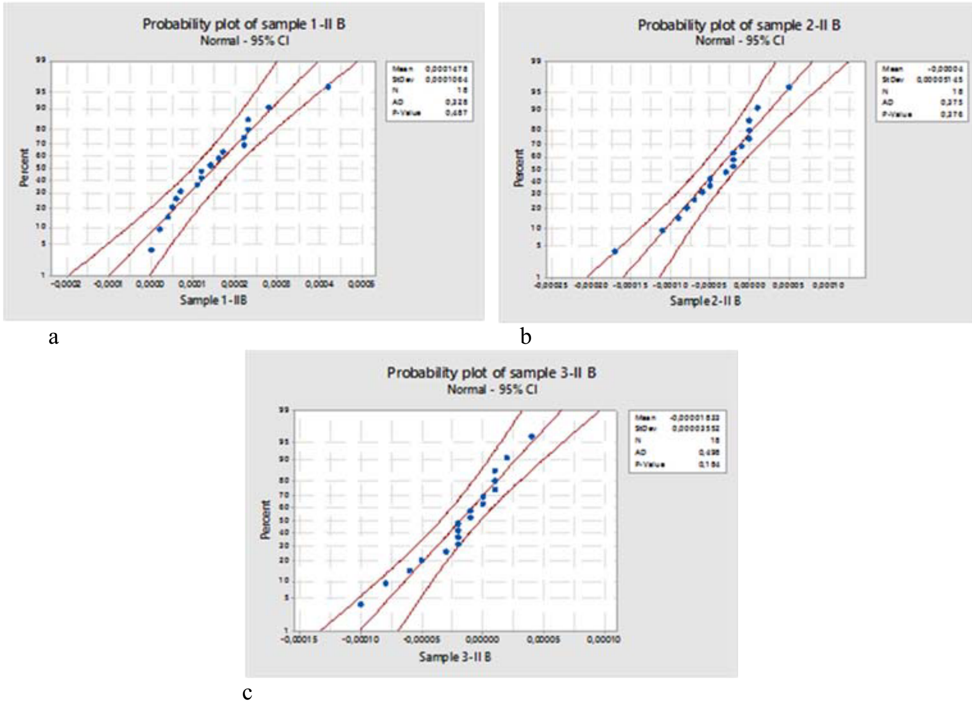


Fig. 3. Probability plots of the samples 1, 2, 3 collected by using water meters of type II, precision class B.

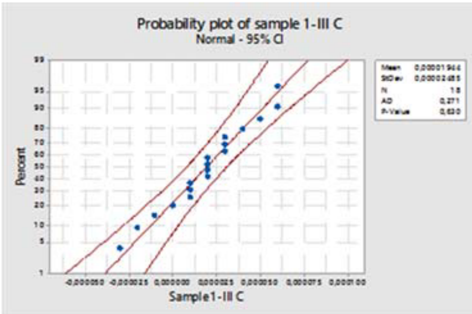
3.3 Water meters of type III, precision class C

The experimental data was collected by reading the indications of the water meters of type III, precision class C. It represents the measurement errors which are resulting by measuring a constant volume of water (10 liters) using the water meters considered.

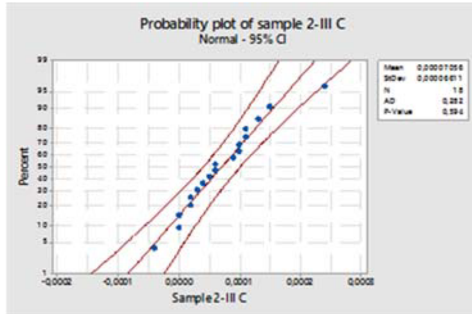
The measurement errors of the water meters of type III, precision class C, are shown in Table 7. The probability plots for each sample are presented in Figure 4, a to c, and normal distribution is assumed in each case. Table 8 presents the estimated values of the parameters of the normal distribution and Table 9 presents the values of the statistics of the goodness of fit tests applied, which are compared to the critical values of the statistics of the goodness of fit tests, $d_{n,\alpha}$ and $L_{n,\alpha}$ [3].

Table 7. Measurement errors of water meters of type III, precision class C.

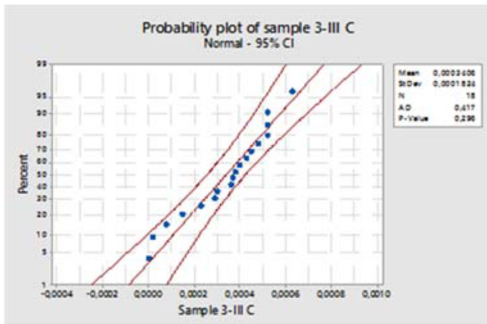
Water meter	Measurement errors (m^3)
1-III C	0, 0.00001, -0.00003, 0.00006, 0.00001, 0.00003, 0.00003, 0.00002, 0.00003, 0.00002, -0.00002, 0.00006, 0.00001, 0.00002, -0.00001, 0.00002, 0.00005, 0.00004
2-III C	0, 0, 0.00003, 0.00024, 0.0001, 0.00002, 0.00011, 0.00011, 0.00015, 0.00013, 0.0001, 0.00004, 0.00006, -0.00004, 0.00005, 0.00009, 0.00002, 0.00006
3-III C	0.00002, 0.00015, 0.00043, 0, 0.00008, 0.00052, 0.00052, 0.00038, 0.0003, 0.00048, 0.00063, 0.00023, 0.00037, 0.00036, 0.0004, 0.00029, 0.00045, 0.00052



a



b



c

Fig. 4. Probability plots of the samples 1, 2, 3 collected by using water meters of type III, precision class C.

Table 8. Parameter estimation - water meters of type III, precision class C.

Water meter	1-III C	2-III C	3-III C
Mean	$m_1 = 0.00002$	$m_2 = 0.00007$	$m_3 = 0.00034$
Standard deviation	$\sigma_1 = 0.0002$	$\sigma_2 = 0.00006$	$\sigma_3 = 0.00018$

Table 9. Validation of the statistical model - water meters of type III, precision class C.

Kolmogorov-Smirnov test: for $d_j \le d_{n,\alpha} = 0.309 \Rightarrow$ the hypothesis of normal distribution is accepted		
$d_1 = 0.1009$	$d_2 = 0.1190$	$d_3 = 0.1536$
Lilliefors test: for $L_j \le L_{n,\alpha} = 0.200 \Rightarrow$ the hypothesis of normal distribution is accepted		
$L_1 = 0.1009$	$L_2 = 0.1190$	$L_3 = 0.1070$

4 Study on the volume of the water loss in the installation

Water meters of precision class C are designed such as to start the correct registration of the water consumption from the minimum starting flow *Qmin* = 15l/h, while in case of the water meters of precision class B, the minimum starting flow is *Qmin* = 30l/h. As a consequence, since water meters of precision class B are apartment water meters, it results that any water consumption which is less than 30l/h will not be correctly registered by the apartment water meter. In case of a block of flats, although apartment water meters might not register correctly the water consumption due to a reduced flow in the apartment installation, the proper consumption will be correcly registered by the branching water meter which is the general water meter for the block of flats. Thus, the water losses are not registered by the apartment water meters and the water consumption is not paid correctly, so that the water company has financial losses.

The volume of the water loss depends on the water flow in the installation. The cases presented below prove this fact.

As to those presented above, a study was conducted using the water meters in the installation described in Figure 1, for determining the volume of the water loss in case the flow is less than $Qmin$=15l/h. It was considered the case of a leakage difficult to detect, when, from time to time, a very small drop of water appeares and falls from the tap. The period of time in which a water loss has occurred is t = 32'53", and the actual water volume collected drop by drop is V=2 l, such as the corresponding water flow Q is:

$$Q = \frac{V}{t} = 0{,}0036\,\mathrm{m}^3/\mathrm{h}\,. \tag{1}$$

Table 10 presents the volume of the water loss, which is not measured by the water meters and the volume of the water loss corresponding to one hour, for water flow Q.

Table 10. Volumes of the water loss registered by the three types of water meters for water flow Q.

Type of water meter	The volume of water registrated (l)	Mean of the volume of water registrated (l)	Actual volume of water (l), corresponding to time t	Volume of water loss (l), corresponding to time t	Volume of water loss (l), corresponding to one hour (1h)
I	0,05	0,03	2	1,97	3,594
	0,04				
	0				
II	0,03	0,02	2	1,98	3,612
	0,01				
	0,02				
III	0,17	0,15	2	1,85	3,375
	0,15				
	0,13				

A second case considers a leakage, still difficult to detect, which ocurred in time t' = 16'35", the volume of water loss being V=2 l, too. The corresponding water flow Q' is:

$$Q' = \frac{V}{t'} = 0{,}0072\,\mathrm{m}^3/\mathrm{h}\,. \tag{2}$$

Table 11 presents the volume of the water loss, which is not measured by the water meters and the volume of the water loss corresponding to one hour, for water flow Q'.

Table 11. Volumes of the water loss registered by the three types of water meters for water flow Q'.

Type of water meter	The volume of water registrated (l)	Mean of the volume of water registrated (l)	Actual volume of water (l), corresponding to time t'	Volume of water loss (l), corresponding to time t'	Volume of water loss (l), corresponding to one hour (1h)
I	0.15	0.16	2	1.84	6.65
	0.17				
	0.16				
II	0.15	0.14	2	1.86	6.72
	0.13				
	0.14				
III	0.56	0.57	2	1.43	5.17
	0.58				
	0,57				

As seen from Table 10 and Table 11, the volume of the water loss depends directly proportional with the water flow in the installation.

5 Conclusions

Water meters, as measuring devices, may measure with errors that are greater than the admissible ones; this leads to errors in the metering of the consumed water and the financial losses are carried by the water company or by the client; on the other side, conditions for the irrational utilization of the potable water resources are created.

The tolerated maximum measuring errors are ±2% for cold water (if water temperature <= 30°C) [5]. As seen in the cases considered in this research, there are measuring errors exceeding the tolerance interval for each type of the water meters analysed and they lead to errors in metering the consumed water.

The errors in metering the consumed water may appear in the period of their utilisation. As to the measuring errors, in the period in which water meters are used, it is possible for these errors to exceed the tolerance interval and if this exceeding represents a certain percentage, corresponding to the established level of significance, a metrological control of the water meters should be performed. As a consequence, it would be necessary to develop an algorithm which would provide information on the moment when the verification would be required for the water meters to remain within the appropriate performance specifications.

Other cause which could lead to errors in metering the consumed volume of water is represented by a water flow in an installation, less than the minimum starting flow of the water meters, which creates conditions for the incorrect registration of the water consumption. In order to solve this problem, one needs to use accurate water meters and leakage detecting equipment

References

1. I. Hohan, *Technology and reliability of the systems* (Ed. Didactică şi Pedagogică, Bucureşti, 1982)
2. I. Martinescu, I. Popescu, *Analysis of the reliability and of the security of the systems* (Ed. Universităţii „Transilvania" Braşov, Braşov, 2002)
3. M.R. Clinciu, *Research on the reliability of the water meters* (Ph.D. Thesis, Transilvania University of Braşov, Braşov, 2009)
4. V.G. Voda, A. Dorin, *Statistical reliability problems* (Ed. Economică, București, 1994)
5. NML 003-05, *Water meters* (Monitorul oficial al României, Bucuresti, 2005)