

# Evaluation of Measurement Uncertainty in Calibration Standard Volumetric Installation for Water Meters Verification

Gabriel Constantin Sârbu

*"Gheorghe Asachi" Technical University of Iasi*  
*Faculty of Hydrotechnics, Geodesy and Environmental Engineering Iasi, Romania*  
[gabrielsarbu26@yahoo.ro](mailto:gabrielsarbu26@yahoo.ro)  
0756 010008

**Abstract** –For the design and construction of an standard volumetric installation for water flowmeters verification/calibration, is taken account of all the metrological, structural and functional characteristics requirements and the measurement uncertainty. All the individual uncertainty components of the volumetric installation for water meters verification should have predefined values and provide for the total expanded measurement uncertainty of the installation a smaller value. For calibration of volumetric installations, standard volume measures are required for secondary calibrations with appropriate nominal values, pipette, thermometer, chronometer. Measurement uncertainty evaluation involves determining the influence factors of the calibration. The main factors of influence are: volume measurement of the installation; the volume correction due to the temperature of the liquid; correction due to liquid evaporation; correction due to leakage.

**Keywords** – Uncertainty of measurement, volumetric installation, calibration, water flowmeter, volume

## I. INTRODUCTION

Volumetric standard installation are normally used with standing start and finish methods due to the difficulty of diverting flow into the tank and controlling the finish of the fill. The technique gives a very high level of repeatability. Drainage time (after the tank is empty) is vitally important. Liquid clingage to the wall can account for a significant part of the volume and takes appreciable time to drain down. It is normal practice therefore to calibrate the tank (including drainage pipework) and establish a consistent drainage time for the calibration. Each tank has this drain time defined and marked on the calibration plate and certificate. For this reason higher viscosity liquids (above 10 cSt) start to give problems of both accuracy and repeatability due to the unpredictable

quantity of liquid left attached to the walls of the tank.

Calibration of water meter installations consists of:

- a. Examination of the external appearance and construction, where it is established whether the assembly of the installation and its components meet the requirements specified in the relevant metrological normative;
- b. The assessment of the volume of the supply tank is done by geometric measurement and shall be 1,5 times the sum of the volumes of vessels (standard volume measures) and the volume of water contained in the hydraulic circuit of the volumetric installation;
- c. Checking the tightness, where it is determined whether the entire hydraulic circuit of the installation is sealed, when it is for 10 minutes, successively in the resting state and then at maximum load;
- d. Determining the volume measurement errors and their associated uncertainty;
- e. Determination of the measurement errors of the flow indicators can be done directly on the calibrated installation if it can measure the flow in dynamic mode, making determinations at the flows specified in the metrological normative applicable to the flow indicator (rotameter, flowmeter);
- f. The determination of the flow instability consists in determining the difference between the maximum and minimum values of the flow rate indicated by the flowmeter, for a minimum period of 5 minutes, for the flow rates at which the flowmeter measurement error was determined;
- g. Checking the operation of the installation with the maximum number of meters for each nominal diameter in order to determine if the installation permits all the samples provided in the applicable metrological norm.

## II. RELATED RESULTS IN THE LITERATURE

International Standards ISO, provides the methods for determining flow in closed pipes and the requirements for the volumetric standard installations for water flowmeters

verification. If these installations are used for verification the water flowmeters subject to legal metrological regulations, they must be periodically calibrated by a laboratory of a national body with regard to basic physical measures (volume and time) and an analysis of influence factors for assessing measurement uncertainty of volume and volume flow-rate.

After the weighing method, the static gauging method in a volumetric tank may be considered as one of the most accurate of all flow-rate measuring methods, particularly if the precautions given are taken. For this reason, it is often used as a Standard or calibration method. When the installation is carefully constructed, maintained and used, an uncertainty of 0,1 % to + 0,2 % (with 95 % confidence limits) may be achieved .[1-3]

Also, in several of ISO documents, are references to evaluation the uncertainty of measurement, documents which provide guidance on calibration methods, the principle and the requirements on the evaluation of the uncertainty measurement in calibration.[4-6]

In the document, NIST ' Water flowmeter Calibration Facility, we have a description of standard installation for water flowmeter calibration with a uncertainty of 0.033%. The document explains the method of operation, the functions of varios component and gives a detailed analysis of the uncertainty of its volume flow measurement rezults.[7]

The study conducted in the PTB laboratory " Hidrodinamic Test Field it led to obtaining an expanded measurement uncertainty o as low as 0.02% of total volumetric flow-rate measurement.[8]

### III. DESCRIPTION OF THE METHOD

Evaluation of measurement uncertainty involves determining the influence factors of the calibration. To determine factors of influence we start from the general equation of measurement, given in ecuation no. (1):

$$V = V_E \cdot [1 + \beta(20 - t)] + \Delta V + \delta V_E + \delta V_{lin} + \delta V_{op} + \delta V_{evap} + \delta V_m \quad (1)$$

Where:

V is the volume of liquid;

$V_E$  Isthe volume of liquid in the standard measure;

$\Delta V$  Isthedifference in volume determined at repeated measurements;

$\delta V_E$  Isthecalibrationuncertainty of the standard measure;

$\delta V_{lin}$  Isthecorrectiondue to nonlinearity (only for measures with ruler on generators);

$\delta V_{op}$  Isthecorrectiondue to reading the liquid level in the standard vessel;

$\delta V_{evap}$  Isthecorrectiondue to evaporation of the liquid

$\delta V_m$  Isthecorrectiondue to leakage.

The main factors of influence are:

a. Volume measurement of the installation:

The uncertainty due to the measurement of the volume is determined with the relation given in equation no.(2):

$$u_{V1} = \sqrt{u_{lin}^2 + \left(\frac{U}{k}\right)^2 + u_{res}^2} \quad (2)$$

where:

$$u_{lin} = i \cdot \frac{(S_{max} - S_{min})}{2 \cdot \sqrt{3}}$$

i is the level read resolution;

$S_{max}$ ,  $S_{min}$ , is the maximum/minimum sensitivitydetermined (only for standard measures with ruler on generators);

U is the extensive uncertainty of calibration of the standard measure of the installation;

$$u_{res} = i \cdot \frac{S}{2\sqrt{3}}, \text{ istheinfluence of thereading of thelevel}$$

(meniscus) of theliquid;

S is the sensitivity of the standard measure.

b. The volume correction due to the temperature of the liquid and the material of the standard measures

The volume correction factor is given by equation (3):

$$f = 1 - \beta(t - 20) \quad (3)$$

Uncertainty associated with it is given in equation no. (4):

$$u_c^2(f) = t^2 \cdot u^2(\beta) + \beta^2 \cdot u^2(t) \quad (4)$$

in which the accuracy of the knowledge of the volume expansion coefficient is  $\pm 0.5 \cdot 10^{-50} \text{C}^{-1}$ , and the uncertainty temperature measurement is gives by equation (5):

$$u(t) = \sqrt{\left(\frac{U}{2}\right)^2 + u_{res}^2} \quad (5)$$

c. Correction due toliquidevaporation  $\delta V_{evap}$

This parameter is taken into account only for installations that work with hot water.

If the technical conditions of the installation tank are met, no correction is required, but it is assumed to induce an uncertainty of 0.03% of the measured water volume, respecting a rectangular probability distribution.

d. correction duetoleakage  $\delta V_m$

If the technical conditions of operation of the installations are observed, no correction is necessary, but it is assumed to induce an uncertainty of 0.03% of the measured water volume, respecting a rectangular probability distribution.

Applying the law of uncertainty propagation results in the following equation no. (6):

$$u^2(V) = c_V^2 u^2(V_E) + c_{\Delta V}^2 u^2(\Delta V) + c_{\delta V}^2 u^2(\delta V_E) + c_{lin}^2 u^2(V_{lin}) + c_{op}^2 u^2(V_{op}) + c_T^2 u^2(V_T) + c_m^2 u^2(V_m) \quad (6)$$

Where:

$$c_{\Delta V} = c_{\delta V} = c_{lin} = c_{op} = c_m = 1$$

$$c_V = 1 - \beta(t - 20)$$

$$c_T = V$$

Table 1. Budget of uncertainties

Source of uncertainty	The value of the standard uncertainty	Sensitivity coefficient
$u_V$ Volume measured	$\sqrt{u_{lin}^2 + (U/k)^2} + 2 \cdot u_{res}^2 + n \cdot u_{res}^2$	$1 - \beta(t - 20)$
$u_{evap}$ Liquidevaporation	$3 \cdot 10^{-4} V$	1
$u_{\delta V_m}$ Leakage	$3 \cdot 10^{-4} V$	1
$u_T$ Volume correction T	$\sqrt{t^2 \cdot u^2(\beta) + \beta^2 \cdot u^2(t)}$	V

## VI. RESULTS AND DISCUSSIONS

The schematic diagram of a volumetric calibration facility used for water meter calibration / verification is shown in Figure 1.

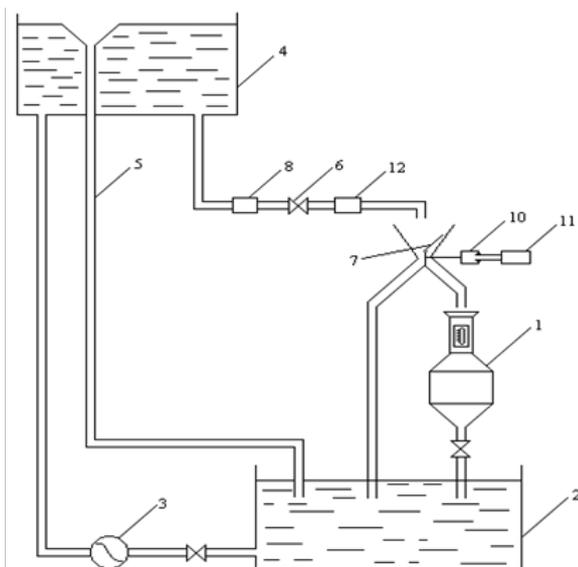


Fig.1. Volumetric installation

1. standard metallic measure volume; 2. storage tank; 3. Pump; 4. constant level reservoir; 5. overflow pipeline; 6. adjusting valve; 7. jet diverter; 8. flow meter / water meter under verification; 9. evacuation valve; 10. contacts; 11. timer;

12. flow indicator.

Using the pump (3) the constant level tank (4) is filled until the liquid flows through the overflow pipe (5). The test flow rate is adjusted by means of the valve (6), which is indicated by the flow indicator (12) (electromagnetic flowmeter, rotameter, etc.).

The installation is provided with a pneumatically operated jet deflector which allows the flow of water submitted to cross flow meter calibration/verification vessel or directly to the storage tank. In order to ensure constant flow in place of the constant level tank, pumps equipped with frequency converters can be used.

Calibration operation involves comparison between the reading taken from a device under test and that of a standard volume measure. It is necessary to consider what properties are required from a standard, firstly and most importantly, the standard should measure the same quantity as the device, comparing a volume meter output with that of a volume tank, and measuring of density to allow conversion between volume and mass.

The measurement of the quantity of liquid collected may be carried out volumetrically by collecting a known volume of liquid in a container. In the volumetric method the standard volume measure takes the form of a tank with a calibrated volume.

Normally this will be a standard metallic measure volume with conical ends to facilitate drainage. The neck of the measure volume is normally fitted with a sight glass and a scale marked in volumetric units. A typical volumetric measure is shown in Figure 1. The volume must be determined by calibration of the metallic measure volume. This can be carried out by weighing the water contained in the tank, or, carried out using smaller volumetric measures which are themselves traceable to national standards by weighing methods. Calibration is usually by filling the vessel with a measured weight of water, or by emptying the vessel into a weighing tank.

For calibration of volumetric installations, standard volume measures are required for secondary calibrations with appropriate nominal values and the subsidiary measurements to determine the fluid conditions, properties and influence factors (pipette, thermometer, timer if the plant has rotameter flow indicators).

Determining the volume measurement errors and their associated uncertainty require:

- calibration of the volume measures with the ruler on the generators is made at a minimum of 5 points, by performing 4 sets of measurements. In the case of double measures consisting of two concentric vessels having a single measuring gauge, the calibration is made in 5 points for the inner vessel, and 3 more points for the outer vessel, situated above the discharge flap of the inner vessel;

- calibration of volume measures with a ruler on the neck is done in 3 points representing  $V_{min}$ ,  $V_{nom}$ ,  $V_{max}$ , printed on the measure ruler, making 4 determinations for each volume;

An example for calculating the uncertainty of volume measurement refers to a volumetric plant equipped with a standard metallic measure volume with two concentric vessels, made of stainless steel, with the ruler on the generators, nominal volume  $V_{n1}= 90 \text{ dm}^3$  and  $V_{n2}= 490 \text{ dm}^3$ . In Table 2, Table 3 and Table 4, I will give the results of the measurement uncertainty calculation for volume.

Table 2. Uncertainty of volume measure calibration  
 $V_{n1}=90 \text{ dm}^3$  ;  $S=0.125 \text{ dm}^3/\text{mm}$

Measured volume		Standard volume	Deviation
mm	$\text{dm}^3$	$\text{dm}^3$	$\text{dm}^3$
79.89	9.99	10.00	-0.01
159.66	19.96	20.00	-0.04
239.63	29.95	30.00	-0.05
319.65	39.96	40.00	-0.04
399.97	50.00	50.00	0.00
479.40	59.93	60.00	-0.07
559.40	69.93	70.00	-0.07
639.50	79.94	80.00	-0.06
719.45	89.93	90.00	-0.07
Average deviation			-0.04
Standard deviation of the average			0.0089
Uncertainty of volume measured			$\pm 0.009$
Uncertainty of standard volume measure			$\pm 0.0008$
Volume Measure Calibration Uncertainty			$\pm 0.010$

Table 3. Uncertainty of volume measure calibration  
 $V_{n1}= 490 \text{ dm}^3$  ;  $S=0.500 \text{ dm}^3/\text{mm}$

Measured volume		Standard volume	Deviation
mm	$\text{dm}^3$	$\text{dm}^3$	$\text{dm}^3$
820.00	410.00	410.00	0.00
839.80	419.90	420.00	-0.10
860.30	430.15	430.00	+0.15
880.05	440.03	440.00	+0.03
899.95	449.98	450.00	-0.02
919.70	459.85	460.00	-0.15
939.70	469.85	470.00	-0.15
959.75	479.86	480.00	-0.14
979.75	489.86	490.00	-0.14
Average deviation			-0.06
Standard deviation of the average			0.033
Uncertainty of volume measured			$\pm 0.033$
Uncertainty of standard volume measure			$\pm 0.019$
Volume Measure Calibration Uncertainty			$\pm 0.038$

Table 4. Volume uncertainty calculation

Uncertainty source	Value $V_{n1}/V_{n2}$ ( $\pm \text{dm}^3$ )	Probab Distrib. Divisor	Standard Uncertainty ( $\pm \text{dm}^3$ )
Uncertainty of volume measure	0.010 0.038	Normal 2	0.0050 0.0190
Uncertainty of liquid evaporation	0.00003 0.00013	Rectangular 1.73	0.000017 0.000075
Uncertainty for leakage	0.0133 0.0667	Normal 2	0.00665 0.03333
Uncertainty of volume correction temperature	0.03460 0.18642	Rectangular 1.73	0.02000 0.10775
Combined volume uncertainty		Normal	0.0198 0.1140
Extended volume uncertainty P= 95%, K =2		Normal	0.0396 0.2280
Volume Uncertainty Calibration (%): $V_{n1}= 90 \text{ dm}^3 \pm 0.044 \%$ $V_{n2}= 490 \text{ dm}^3 \pm 0.047 \%$			

Given the uncertainties of the sub-components such as those for volume collected, the collection time and the density of the water flowing through the meter under verification during the collection which must be combined to obtain the volume flow rate uncertainties, or the mass flow rate, if this is desired.

Calculation of volume flow measurements uncertainty is based by combining the volume uncertainty and collection time uncertainty using the root-sum-squared technique, given in Table 5:

Table 5. Volume flow uncertainty calculation

Uncertainty source	Uncertainty ( $\pm \%$ )	
Volume collected ( $\text{dm}^3$ )	90.00	490.00
Volume uncertainty	0.044	0.047
Collected time uncertainty	0.01	0.01
Water density uncertainty	0.005	0.005
Volume flow uncertainty	0.045	0.048
Expanded volume flow uncertainty P= 95% K= 2	0.090	0.092
Mass flow uncertainty	0.0453	0.0483
Expanded mass flow uncertainty P= 95% K=2	0.091	0.097

## V. CONCLUSIONS

For evaluation of measurement uncertainty in calibration standard volumetric installation for water meter verification/calibration, is necessary in the design and construction of a standard volumetric installation for water meters verification/calibration, to be taken into account of all metrological, constructive and functional requirements and uncertainty.

All the individual uncertainty components of the volumetric installation for water meters verification

should have predefined values and provide for the total expanded measurement uncertainty of the installation a smaller value.

Measurement uncertainty evaluation involves determining the influence factors of the calibration. To determine factors of influence we start from the general equation of measurement(1).The main factors of influence are: volume measurement of the installation; the volume correction due to the temperature of the liquid and the material of the volume standard measures; correction due to liquid evaporation; correction due to leakage.

After the weighing method, the volumetric method in may be considered as one of the most accurate of all flow-rate measuring methods. With a well-built, maintained and careful installation, an extended uncertainty (for confidence probability of 95%) can be achieved in the order of  $\pm 0.09\%$ .

#### REFERENCES

- [1] ISO4185(1980),Liquids flow measurement in closed pipes
- [2] ISO 5168, Fluids flow measurement – Accuracy calculus
- [3] ISO8316:1987, *Measurement of Liquid Flow In Closed Conduits – Method By Collection of The Liquid In A Volumetric Tank*
- [4] ISO-GUM,*Guide to the Expression of Uncertainty in Measurement.*
- [5] SR13434,*Guide for evaluating and expressing uncertainty in measurement.*
- [6] EA-4/02,*Expression of the Uncertainty of Measurement in Calibration*
- [7] Shinder I,Marfenko I,*NIST'-Water flowmeter Calibration Facility*, NIST Special Publication 250
- [8] Engel R,Baade H.J,Rubel A, *Performance improvement of liquid flow calibration by applying special measurement and control strategies*, The 11th International Conference on Flow Measurement FLOMENKO 2003
- [9] Costea O, Donciu C, *Labview based analog and digital instrument's automated calibration*, Management of Technological Changes, vol. 1, pp. 473-476, 2009
- [10] Popescu Șt, Marcoie N, Toma D, *Modelling of a hydrophore pumping facility in slow variable operational regimes*, Buletinul Institutului Politehnic din Iași, Tomul LIV (LVIII), Fasc. 2, pag. 57-66, 2008
- [11] Toma D, *Issues related to the adapting of variable operating regime pumping plants by the use of variable speed drives*, "Ovidius" University Annals - Constantza, Year XIV, Issue 14, Series: Civil Engineering, ISSN 1584-5990, pp. 111-119, 2012
- [12] Beniugă O, Neacsu O, *Virtual instrumentation system for remote reading of digital and analogical equipment display*, AWERProcedia Information Technology & Computer Science. [Online]. 2013,3, pp.1087-1092. Proceedings of 3rd World Conference on Information Technology (WCIT 2012), 14-16 November, University of Barcelon, Barcelona, Spain