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Chapter 6

Error in Water Meter Measuring Due to Shorter Flow and Consumption Shorter Than the Time the Meter was Calibrated

Dr. Lajos Hovany

Additional information is available at the end of the chapter

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1. Introduction

In line with the Measurement Protocol for Water Meters in the Republic of Serbia, a water meter is declared unreliable for water volume measuring at flow rates lower than Q_{min} [1-3]. For a 20 mm rated diameter water meter, used in the households of this country, the minimum flow is about Q_{min}=0.016-0.060 m^3/hour. Therefore, water volume is measured unreliably due to leakage at the tap, with a flow of 0.003-0.007 m^3/h (drop by drop) and 0.010-0.016 m^3/h (jet), at the bathroom tap at 0.010-0.014 m^3/h (in a very thin jet), and at the toilet tank at 0.004-0.025 m^3/h. As a solution to this problem, the installation of impulse valve, unmeasured-flow reducer, known as UFR, at the water meter is recommended since 2007.

UFR operates based on the difference between the upstream and downstream pressure of 0,4 bar at the valve. For pressure lower than the declared, the UFR closes flow through the water meter, since the spring force is stronger than the force generated by the difference in upstream and downstream pressure. Due to water losses through pipeline leakage, the difference in pressure exceeds the limit value, hence the UFR opens, providing flow at a rate of at least Q_{min} which is then registered by the water meter. UFR manufactured by A.R.I. from Jerusalem is used for adjusting water volume measuring at flow rates lower than 0.026 m^3/h.

The papers published so far refer to measurements obtained on individual water meters and on segments of pipelines.

Operation of 33 water meters with UFR was tested in a calibration laboratory in Udine (Italy) [5]. The water meters had a rated diameter of 20 mm, class C, Q_{min}=0.025 m^3/h, each 1 to 7

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years old. In joint operation of water meters with URF a higher water volume was measured: it was 94% in cases of stagnating water meter propellers, 31.8% for flow rates at the commencement of the propeller rotation (further designated as Q_a) and 14.4% for Q_{min}. The valve's most significant contribution was defined for flow at water meter propeller still-stand. Due to the characteristics of water meters installed in the Republic of Serbia, a similar research is necessary for water meters with 0.025 $m^3/h<Q_{min}<0.060$ m^3/h.

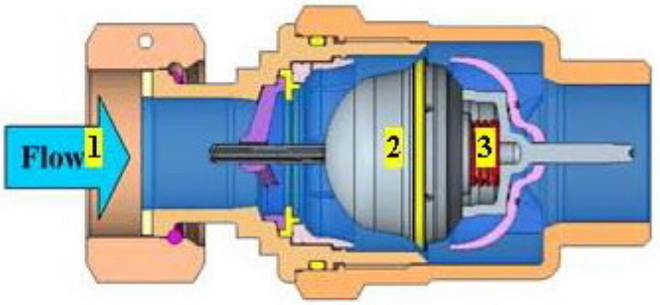


Figure 1. Structure of the UFR- manufactured by A.R.I. from Jerusalem (Israel) [4] 1 - flow direction, 2 - UFR plug, 3 - UFR spring.

Tests were made on parts of the water distribution pipeline in Jerusalem, Larnaca (Cyprus), on Malta, in Kingston (Tennessee, USA) and in Palermo (Italy). Each testing has been carried out with two water balancing: one with and another without UFR in operation. By comparing the results of the balancing obtained for the mentioned statuses, the contribution of UFR to measuring water volume by water meter was determined.

Testing was also implemented in Jerusalem from March 2005 in a duration of 14 months (8 months without UFR and 6 months with UFR) on two systems, where the first comprised 120 and the second 360 water meters [4, 6]. The used class B water meters were with the following characteristics: Q_a=0.012 m^3/h, Q_{min}=0.050 m^3/h and nominal flow Q_n=2.5 m^3/h. With the usage of UFR, the measured water volume was higher for 16.0-6.1=9.9% (on the system with 120 water meters) and for 26.0-18.8=7.2% (on the system with 360 water meters).

From October through December 2006, a water supply system with 280, class B and C water meters, age over 1-15 years was tested in Larnaca with weekly balancing [6]. The water volume measured with UFR was higher for 19.58-9.66=9.92%.

Three tests were made on a system with 26 households on Malta [7-8]. The class D water meters with rated flow of 1 m^3/h were 5 years old in average. The time interval for water balancing was one week. The quantity of water measured by UFR on water meters was more for 26.7-21.2=5.5%, 28-22.2=5.8% and 18.1-12.1=6% than without the use of this valve.

UFRs were installed in a part of a supply network with 35 water meters in Kingston from June 6 to 10, 2008 [9]. The water meters (aged about 4 years) were calibrated prior to the

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measuring. During the operation with URF a higher water consumption was measured: 10.4% for July 2008, 9.5% for August 2008, 4.9% for September 2008, 11.9% for October 2008, 7.6% for November 2008, 8.9% for December 2008, 3.9% for January 2009, 8.4% for February 2009 and 11.6% for March 2009.

Two balancing were made on a part of the supply network with 52 water meters in Palermo: from October 24 through November 14, 2008 without UFR and from December 12, 2008 through January 9, 2009 with UFR [10]. The water meters with 15 mm rated diameter were either 11 years old (33, class C) or older (17 of class B and 2 of class A). During the operation with UFR, the measured volume of consumed water was higher for 28.06-18.91=9.15%.

The use of UFR facilitates the measuring of water consumption at flow rates lower than Q_{min}.

By fulfilling the condition, that the flow of supply network water losses is below 0.026 m^3/h and that water consumption exceeds Q_{min}, a water supply network for a single household was set up in the Hydraulic Laboratory of the faculty of Civil Engineering in Subotica. The aim of the test was to confirm the contribution of UFR in measuring water volume by water meter with 20 mm rated diameter and flow of 0.026 $m^3/h<Q_{min}<0.060$ m^3/h.

ARI from Jerusalem manufactures UFR with 20 mm rated diameter in three types, designed T10, T20 and T30. Thus, conclusions of testing with valve type T30 could also be controlled by valve types T10 and T20.

Class	Water discharge	Discharged water volume	Permitted error limit		Time between two readings
	m^3/h	litres	±%	± litres	minutes
A	Q_{min}=0.06	10	5	0.5	10
	Q_t=0.15	25	2	0.5	10
	Q_n=1.5	100	2	2	4
B	Q_{min}=0.03	5	5	0.25	10
	Q_t=0.12	25	2	0.5	12.5
	Q_n=1.5	100	2	2	4
A	Q_{min}=0.1	20	5	1	12
	Q_t=0.25	30	2	0.6	7.2
	Q_n=2.5	100	2	2	2.4
B	Q_{min}=0.05	20	5	1	24
	Q_t=0.2	25	2	0.5	7.5
	Q_n=2.5	100	2	2	2.4

Table 1. Water volume and calibrated time of water meter of 20 mm rated diameter in the function of typical flows and water meter class.

In line with the Measurement Protocol for Water Meters in the Republic of Serbia, a water meter for water consumption in households is qualified for operation with error below the permitted values, i.e. from ±5% (for Q_{min}) and ±2% (for Q_n and Q_t) from the actual water volume [11]. During calibration, water meter operation errors are checked for the foreseen water volumes.

Through this water volume and discharge, the time for which the meter is calibrated was calculated.

To eliminate the effects of opening and closing the flow switch to measuring errors during calibration, the standard in force in the Republic of Serbia stipulates the following: „The uncertainty introduced into the volume may be considered negligible if the times of motion of the flow switch in each direction are identical within 5% and if this time is less than 1/50 of the total time of the test" [12]. The same recommendations are given by other standards as well [13-14]. Based on that, the following is recommended: „Should there be doubts about whether the operation time of the valve affects the results of the tests, it is recommended that the tests should be made longer, and never under 60 seconds" [15]. That is to say, for neglecting the impact of flow switch manipulation on the water meter's measuring errors the standards offer a solution during the calibration of water meter only.

Water consumption in a single household is implemented by the use of taps, washing machine, dishwasher-machine and shower in the bathroom, likewise the flushing cistern of the toilet and the like. Each consumption is characterised by the opening and closing of flow switch and the duration of water discharge from the pipeline in order to satisfy needs. The duration of consumption in households is shorter than 1 minute in 95% of consumption cases [16]. The error in measuring consumption by water meter, due to manipulating the flow switch, practically manifests as an error due to the duration of consumption shorter than the time the meter was calibrated for [17].

Owing to this fact, the primary aim of this paper is to define measuring errors of consumption shorter than 10 (for Q_{min}), 12.5 (for Q_t) and 4 minutes (for Q_n) of class B water meter with 20 mm rated diameter and flow of Q_n=1.5 m^3/h, installed in the water supply pipeline of a single household.

Water meter operation error depends on water meter reading accuracy [18]. The further aim of this paper is to define water consumption measuring error in households shorter than the time the meter was calibrated for, in the function of water meter reading accuracy.

2. The description of the test rig and the tested statuses

In 2010 and 2011, a test rig was set up in the Hydraulic Laboratory of the Faculty of Civil Engineering in Subotica with two-outlets and consumption and water losses were measured by water meters no. 2 and 3.

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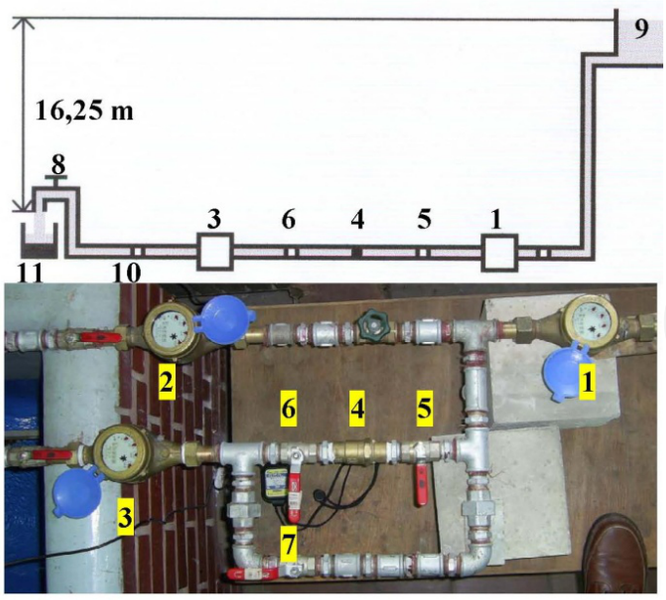


Figure 2. The test rig for water balancing by water maters on water supply system in the Hydraulic Laboratory of the Faculty of Civil Engineering in Subotica 1-3 - water meters, 4 - UFR, 5-8 - shut-off valve, 9 - storage tank, 10 - outlet pipe of water meter no. 3, 11 - balance with a bucket to measure the quantity of water flown through water meter no. 3.

The elements of water balance in the rig were as follows: the volume of the inflow water (measured by water meter no. 1), legal consumption billed and measured (measured by water meter no. 2) and the total volume of water losses, which occurred due to the water meter's inaccurate measuring of flow rates lower than Q_{min} (measured by water meter no. 3).

The operation of the UFR was regulated by shut off valves no. 5, 6 and 7, for example, by shutting down valves no. 5 and 6, the UFR was set out of operation.

Water volumes flown through water meters no. 1, 2 and 3 were defined by the difference of two water meter readings. By measuring time (with stopwatch) between two readings, flows Q_1, Q_2 and Q_3 were calculated by means of the defined water volume. The weight of the water flown through water meter no. 3 was measured by a bucket (16 litres) on a scale. The volume of the water was calculated by the density of the water measured by scale and measuring cylinder.

For the test rig for water balancing in a water supply system, new, calibrated multi-jet propeller water meters with wet mechanism were installed for water temperature of 30°C, and with rated diameter of 20 mm, class B, with the following typical flow rates: Q_a<0.01 m^3/h, Q_{min}=0.03 m^3/h, Q_t=0.12 m^3/h and Q_n=1.5 m^3/h.

The used UFR was manufactured by A.R.I. from Jerusalem, with a rated diameter of 20 mm, product type T30. It was installed upstream to water meter no. 3. In line with the manufacturer's recommendation, in order to provide smooth operation of the UFR between water meter no. 3 and shut off valve no. 8, a 6 m long discharge pipe was installed (marked as no. 10 in the attachment).

Water was brought from the reservoir to the rig by gravitation. According to the pressure and flow rate, the rig complied with a single household water supply pipeline.

Two statuses were tested: a) $Q_2=0$ and b) $Q_{min} \leq Q_2 \leq Q_n$.

Under the Regulations on the Measurement Protocol for Water Meters of the Republic of Serbia, measuring error of a water meter is defined as:

$$G = \frac{100(Vi - Vc)}{Vc} (\%) \quad (1)$$

where:

Vi - water volume flown through the water meter, registered on the meter's counter, and

Vc - water volume flown through the water meter, measured in the bucket on the scale.

The errors changes in the operation of the water meter for status $Q_2=0$ were tested for flow rates $Q_3<0.026$ m^3/h for two cases: without UFR and with UFR in operation at water meter no. 3. Applying the criterion, that the error in the water meter's operation is lower than

$$G \leq G_{av} \pm \sigma \, (\%) \quad (2)$$

where:

G_{av} - is the mean error of the water meter in case of steady flow, and

σ - is the standard deviation of the water meter error in steady state flow,

the time needed for getting steady flow, t_{st}, was defined.

After the time required for establishing steady flow t_{st} was determined, the error in water balancing for status $Q_{min} \leq Q_2 \leq Q_n$ and flow rate Q_3 was investigated by the rig:

$$G_b = \frac{100(V_2 + V_3 - V_1)}{V_1} (\%) \quad (3)$$

where:

$V_1 = Q_1 * t_{st}$ - water volume at intake,

$V_2 + V_3 = Q_2 * t_{st} + Q_3 * t_{st}$ - water volume at outlet, and

t_{st} - time for establishing steady flow at water meter no. 3.

The error in balancing was checked for four values of flow rate Q_2 - for two flow rates when $Q_{min} \leq Q_2 \leq Q_t$ and for two flow rates when $Q_t \leq Q_2 \leq Q_n$. The series comprised of 1 to 30 measurements.

Errors in balancing are caused by errors in operation of water meters for measuring water volume: up to ±5% for $Q_{min} \leq (Q_1$ and $Q_2) \leq Q_t$ and up to ±2% for $Q_t \leq (Q_1$ and $Q_2) \leq Q_n$, and unde-

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termined values for $Q_3<Q_{min}$. Since flow rate Q_3 has always been lower than Q_{min}, there is no permitted balancing error limit for the tested statuses.

During accuracy measurements, water meter readings were 2.5 centilitres. Measurement accuracy of water quantity in the vessel was 0.005 kg.

Error in water meter measuring due to consumption shorter than the time the meter was calibrated for: a water supply pipeline was set up in the Hydraulic Laboratory of the Faculty of Civil Engineering in Subotica (in 2011 and 2012), gravitationally supplied from a tank with constant water level, i.e. for 16.25 m higher than the level of the water meter axis. According to both water flow and the water supply pipeline characteristics, the water supply pipeline corresponds to the one of a single household.



Figure 3. Part of the water supply pipeline downstream from the water meter (1) in the Hydraulic Laboratory of the Faculty of Civil Engineering in Subotica. 2 - stop valve, 3 - vessel with scale for measuring water quantity flown through the water meter, 4 - stop-watch, 5 - measuring cylinder and thermometer, 6 - manometer.

During calibration, the reading accuracy of the water meter was 1 decilitre.

A stop valve for starting and stopping water flow was installed at 2.8 m downstream from the water meter.

Water volume flown through the water meter was defined by:

- the difference in reading on the water meter prior and after measuring, and
- measuring water quantity in the vessel (of 15 to 200 litres in volume) and water density.

By measuring time (with stop-watch) between two readings, through the defined water volume in the vessel, the water flow rate Q was calculated.

During accuracy measurements, water meter readings were as follows: 2.5 centilitres, 1 decilitre and 1 litre. Measurement accuracy of water quantity in the vessel was 0.005 kg (for Q_{min}), 0.01 kg (for Q_t) and 0.1 kg (for Q_n).

Error changes in the operation of the water meter described by equation (1), were tested by applying two method by stopping the water meter: according to the valid Protocol of the Republic of Serbia, the status on the water meter and the scale was read prior and after measuring at water meter propeller in stillstand [12].

3. Results

The error changes (G) in the operation of the water meter for status Q_2=0 were tested for two cases: without UFR and with UFR in operation at water meter no. 3.

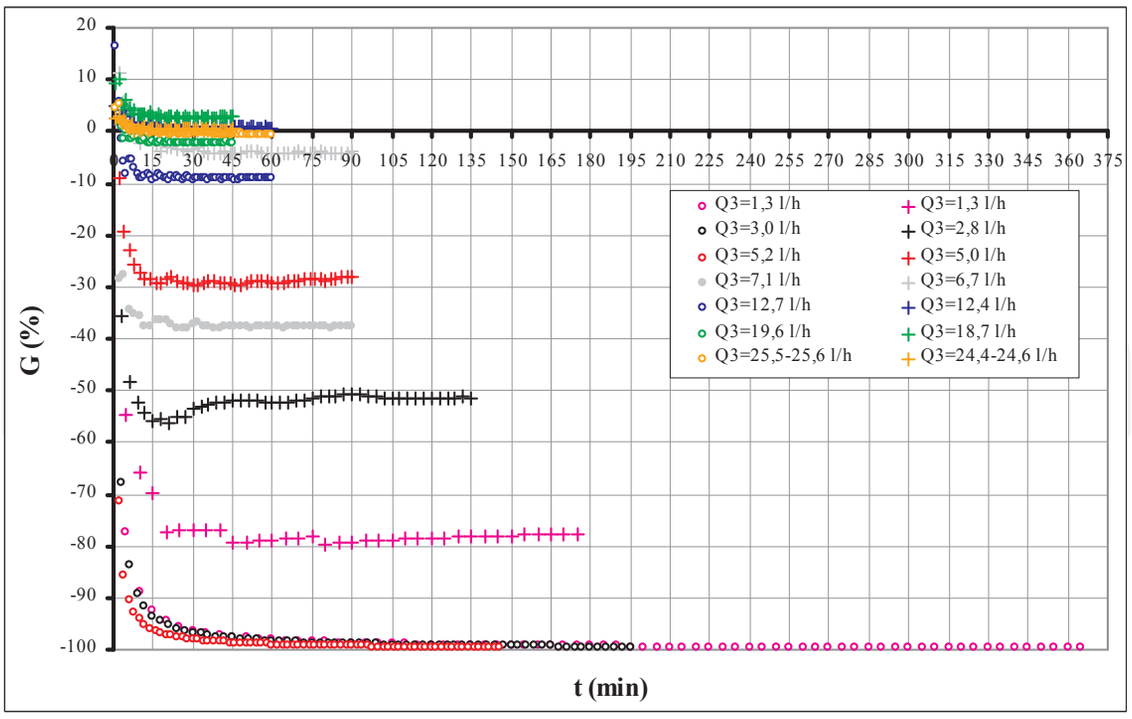


Figure 4. Error changes (G) in the operation of water meter no. 3 during time in the function of Q_3 flow without UFR in operation (circles) and with the UFR in operation (crosses).

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With the criterion described by equation (2), steady state flow stabilisation time, t_{st} was defined:

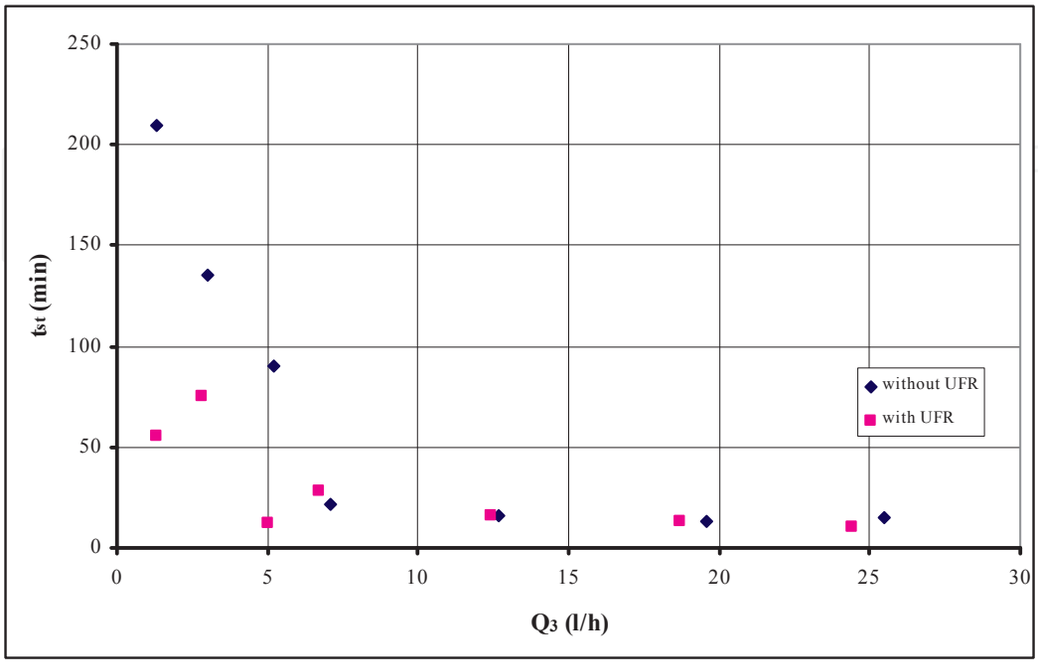


Figure 5. Stabilisation time of water flow in the installation t_{st} in the function of flow Q_3.

Q_3 l/h	t_{st} (min.) without UFR
25.5	15
19.6	13
12.7	16
7.1	22
5.2	90
3	135
1.3	210
Q_3 l/h	**t_{st} (min.) with UFR**
24.4	10
18.7	13
12.4	16
6.7	28
5	12
2.8	75
1.3	55

Table 2. Stabilisation time of water flow in the installation t_{st} in the function of flow Q_3.

Error in the operation of water meter at steady state flow defined by equation (1) is:

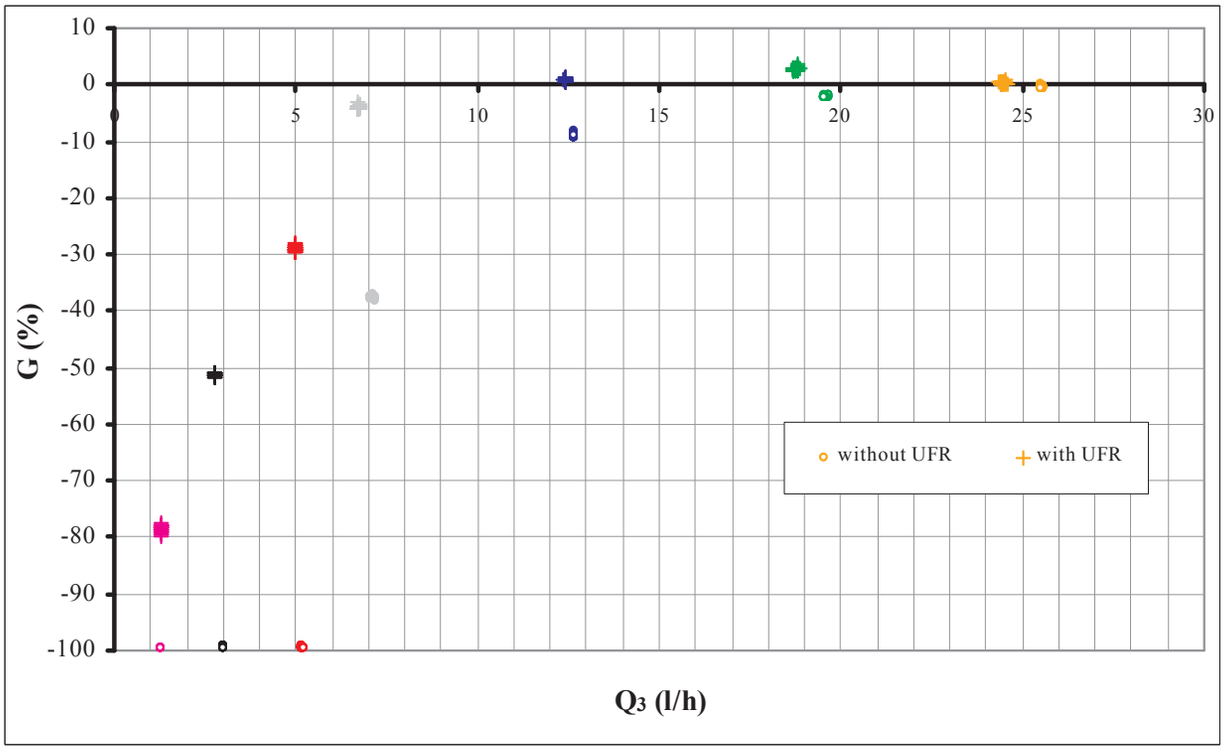


Figure 6. Error (G) in the operation of water meter no. 3 at steady state flow in function of flow rate Q_3, without UFR and with UFR.

The error in the operation of water meter no. 3 without UFR is bigger than with UFR.

The measurements proved that Q_a<0.01 m^3/h is between 0.0052 and 0.0067 m^3/h.

By increasing flow rate Q_3 towards flow rate Q_a, the influence of UFR operation on measuring water volume increases: for Q_3=0.0013 m^3/h the contribution is 99.59-78.49=21.1%, and for Q_3=0.005-0.0052 m^3/h it is 99.5-28.93=70.57%. For flow rates Q_3>Q_a up to Q_3=0.026 m^3/h the contribution of UFR to measuring water volume by water meter is decreasing: for flow rate Q_3=0.0067-0.0071 m^3/h the contribution is 37.67-4.07=33.6%, and for Q_3=0.0244-0.0255 m^3/h it is 0.47+0.36=0.83%.

Without the UFR in operation, the water meter always shows lower water volume than the real value. With the UFR in operation, at flow rate Q_3=0.01 m^3/h, the operation of the water meter is changing: for flow rate Q_3<0.01 m^3/h the water meter shows lower volume than the real value, while for Q_3>0.01 m^3/h it shows higher value (not exceeding 2.7%) than the real one.

For status $Q_{min} \leq Q_2 \leq Q_n$ balancing errors described by equation (3) are:

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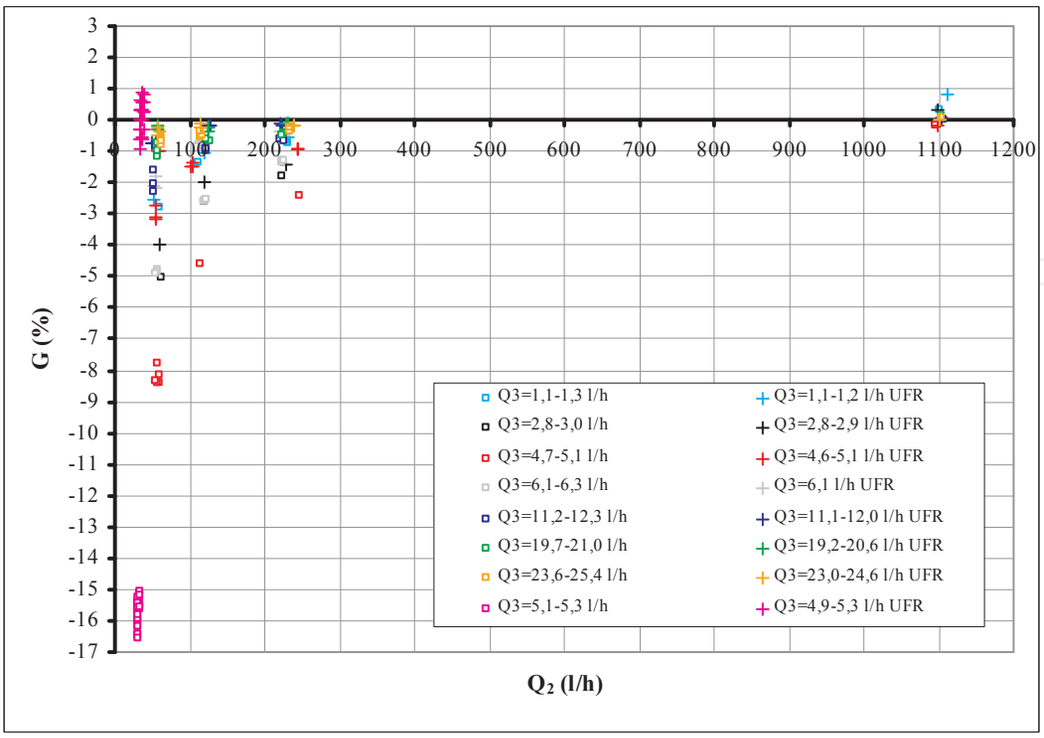


Figure 7. Error (G_b) in water balancing on the rig in the function of flow rates Q_2 and Q_3, without UFR (left) and with UFR (right) in operation.

The highest balancing error values for the tested statuses are +0.9 and -16.6%. By increasing flow rate Q_2 for both statuses (without UFR and with UFR at water meter no. 3) errors in balancing decrease.

With UFR in operation, the most significant contribution in measuring water volume by water meter (15.7-0=15.7%, mean value of 30 measurments) was determined at operations at flow rates Q_2=0.03-0.0385 m^3/h and Q_3=0.0049-0.0053 m^3/h.

At steady flow slightly lesser than Q_a, UFR efficiency increases from T10 to T30: water meter equipped with UFR type T10 measures for 99.53-84.14=15.39% more water than in status without UFR, while the increase with type T20 is 99.33-68.55=30.78% and with type T30 it is 99.5-28.93=70.57%.

This conclusion was verified for a single household water supply network by the results of five measurements for each status: water meter equipped with type T10 UFR measured (at flow rates Q_2=51.3-51.4 l/h and Q_3=5.2-5.6 l/h) maximum 9.89-6.84=3.05% more water consumption of than without UFR, with type T20 (at flow rate of Q_2=56.9-60 l/h and Q_3=5.3-5.5 l/h) the most significant improvement was 9.06-4.19=4.87%, while with type T30 (at flow rates of Q_2=55.9-58.5 l/h and Q_3=4.9-5.1 l/h) the result is 8.4-0.97=7.43%.

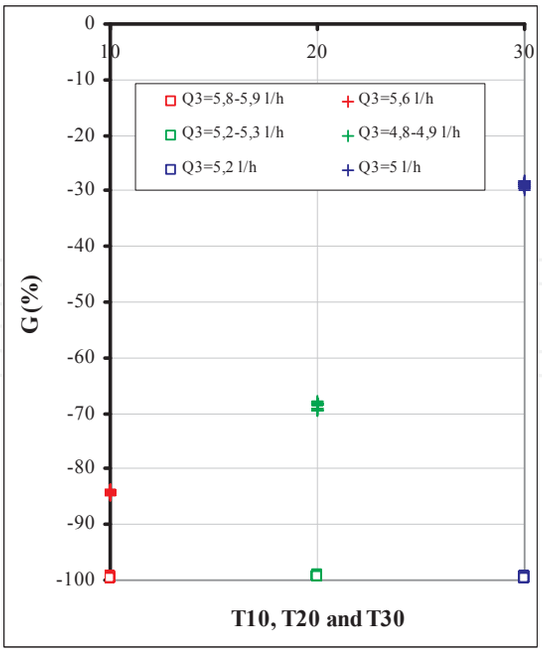


Figure 8. Error (G) in the operation of water meter no. 3 at steady state flow in function of flow rate $Q_3=Q_a$ without UFR (left) and with UFR (right) type T10, T20 and T30.

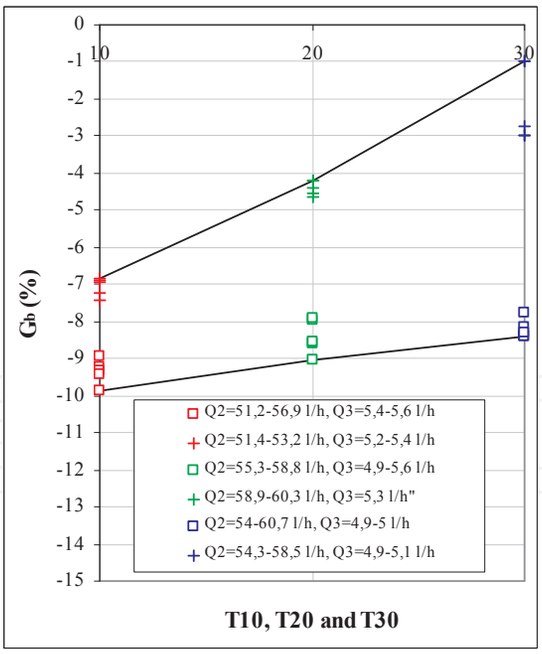


Figure 9. Water balance error (G_b) of the tested water supply network without UFR type T10, T20 and T30 (quadrat) and equipped with one of the UFR type (cross).

Error in water meter measuring due to consumption shorter than the time the meter was calibrated for: each measurement was repeated 5-30 times.

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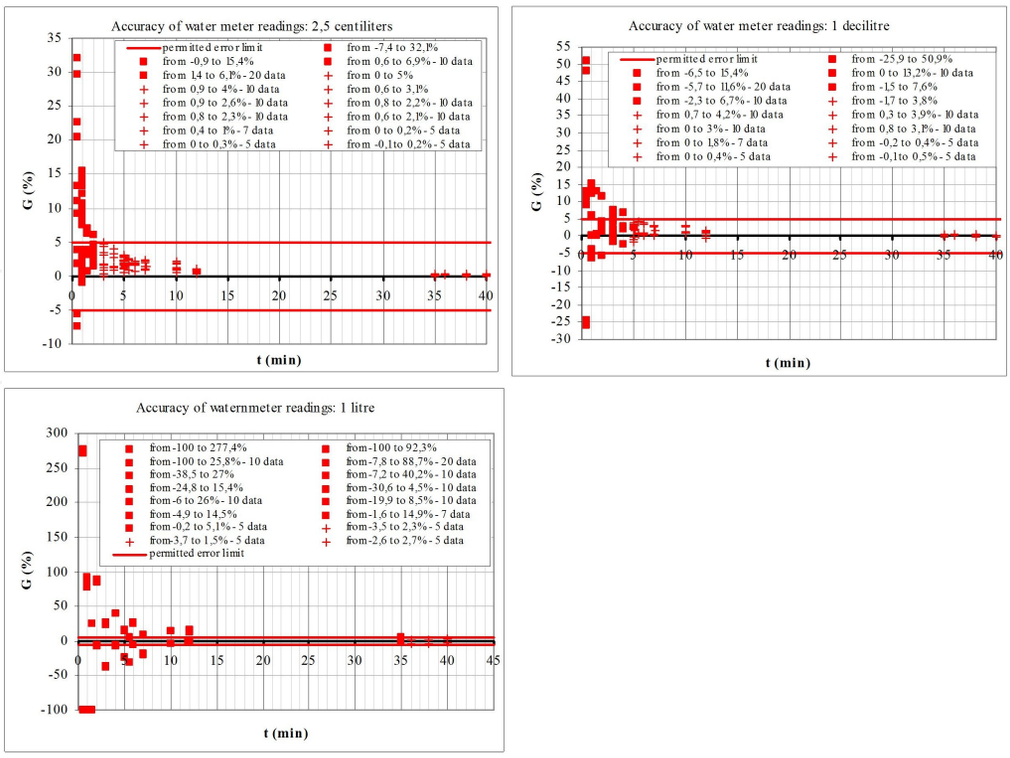


Figure 10. Error in water meter measuring at Q_{min} flow during water flow shorter than the time for which the meter was calibrated (10 min.) in the function of water meter reading accuracy.

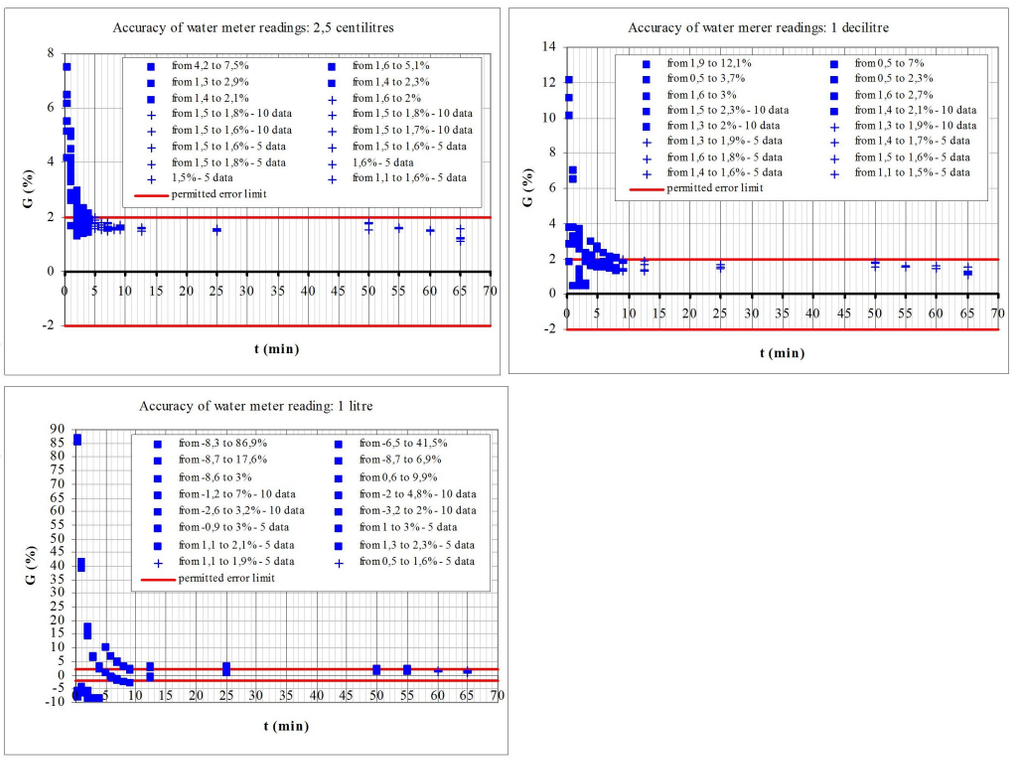


Figure 11. Error in water meter measuring at Q_t flow during water flow shorter than the time for which the meter was calibrated (12.5 min.) in the function of water meter reading accuracy.

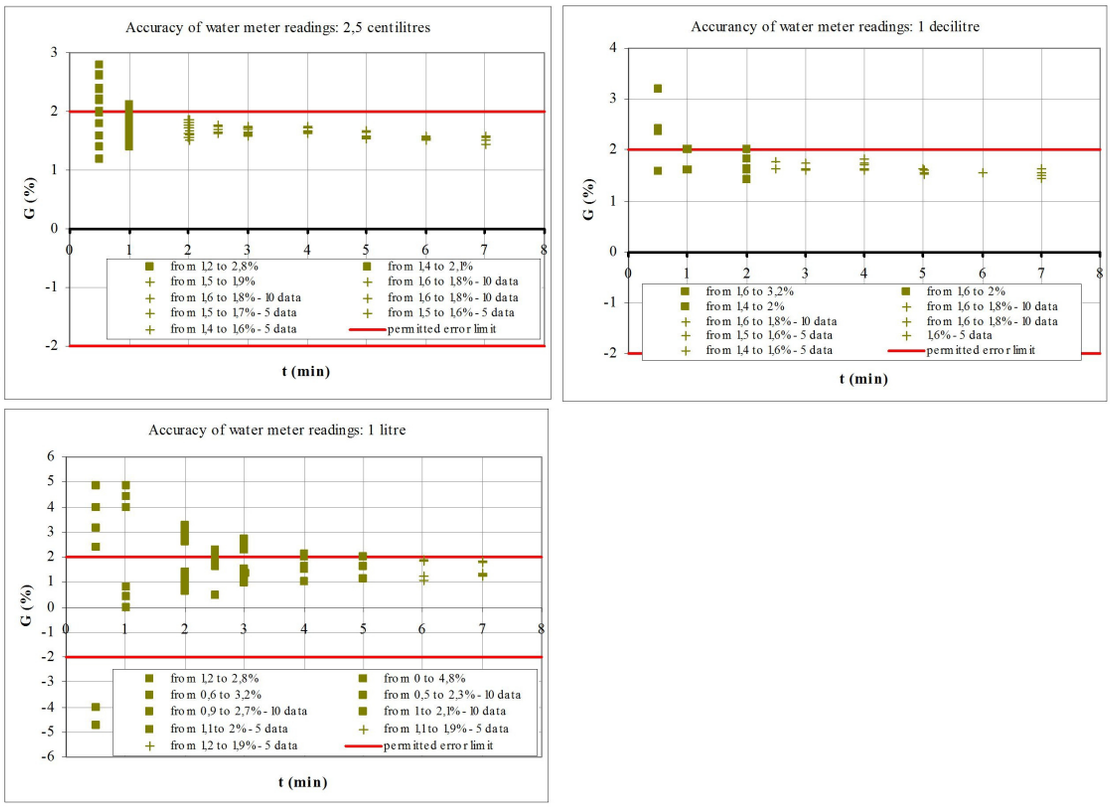


Figure 12. Error in water meter measuring at Q_n flow during water flow shorter than the time for which the meter was calibrated (4 min.) in the function of water meter reading accuracy.

The minimum time at which measuring errors undoubtedly are within the permitted limit is defined for the calibrated flows of the water meter as follows:

Reading accuracy	Dis-charge	Minimum time (minutes)
2.5 centilitres	Q_{min}	3
	Q_t	5
	Q_n	2
1 decilitre	Q_{min}	5
	Q_t	9
	Q_n	2.5
1 litre	Q_{min}	36
	Q_t	60
	Q_n	6

Table 3. Minimum calibrated flow duration time in the function of reading accuracy.

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4. Discussion

Measurement results confirm and specify the conclusions of tests made in Udine in relation to the contribution of UFR to water meter operation: a) that the most significant contribution is at flow, when water meter propeller is steady (specifically for Q_a), and b) that this contribution is decreasing from flow Q_a towards flow Q_{min}.

The same conclusion is valid for test results on the UFR contribution at parts of the water supply network. Providing similar water consumption during testings on the test rig without UFR and with UFR enabled specifying the results.

In the case, when consumption time was shorter than the time the meter was calibrated for, the range of the meter measuring error exceeded the range of permitted errors.

Reading Accuracy	Discharge	Error range (%)	
		During experiment	During calibration
2.5 centilitar	Q_{min}	from -7.4 to 32.1	
	Q_t	from 4.2 to 7.5	
	Q_n	from 1.2 to 2.8	
1 decilitar	Q_{min}	from -25.9 to 50.9	±5
	Q_t	from 1.9 to 12.1	±2
	Q_n	from 1.6 to 3.2	±2
1 litar	Q_{min}	from -100 to 277.4	
	Q_t	from -8.3 to 86.9	
	Q_n	from -4.8 to 4.8	

Table 4. Error ranges of water meter measuring for calibrated discharges in the function of water meter reading accuracy (class B, rated diameter of 20 mm and discharge of Q_n=1.5 m^3/h), for a duration of 0.5 minutes flow.

It means that during consumption shorter than the time the water meter was calibrated for, measuring by the meter is unreliable in 95% of the consumption shorter than 1 minute. During a discharge of 0.5 minutes, the error may be even 277.4%.

In order to improve water consumption measuring in households, it is necessary to provide conditions for measuring consumption at flow lower than Q_{min} and duration shorter than the time the meter has been calibrated for. Such conditions may be created in supply pipelines with water storage tanks in households. Only such systems are appropriate in which all the water needed in a household flows through this storage tank [19].

The UFR should be installed on the outlet pipe from the tank to the household. Signalising the start of the UFR's operation may initiate works on eliminating water losses due to leakage on the tap, bathroom battery and the flushing cistern. This way, the use of UFR would serve to protect the interest of the households.

Recently, it has been a frequent practice, that a water meter is installed on the inlet pipe of the storage tank near the building [10, 20-25]. Such water meters provide the opportunity to ensure a minimum period of time, at which water meter measurement error surely stays within the permitted error limit.

By solving water quality problems in these storage tanks, the above mentioned conditions will, first and foremost, be provided in settlements already having such water supply networks in place, e.g. in settlements without continuous potable water supply (e.g. in Mozambique, Yemen, Jordanian, Lebanon, Palestine, on the Mediterranean in Europe) and in water supply networks designed in the XIXth century (e.g. the UK) [21, 23, 26-30].

5. Conclusion

According to pressure and water flow rate, the test rig in the Hydraulic Laboratory of the Faculty of Civil Engineering Subotica presented a case of a single household water pipeline. The water meters are produced by Potiski vodovodi Ltd. from Horgos with rated diameter of 20 mm, class B, and the following flow rate characteristics: the flow at starting the water meter propeller (Q_a) is between 0.0052 and 0.0067 m^3/h, Q_{min}=0.03 m^3/h, Q_t=0.12 m^3/h and Q_n=1.5 m^3/h. Upstream from water meter no. 3 an UFR was installed, manufactured by A.R.I. from Jerusalem, with rated diameter of 20 mm, product type T30.

During accuracy measurements, water meter readings were 2.5 centilitres. Measurement accuracy of water quantity in the vessel was 0.005 kg.

According to the measurement results, the most significant contribution of the UFR in measuring water volume by a water meter of a single household takes place at water losses by flow rate Q_a, prior to starting the water meter propeller:

a) 70.57% at flow rates Q_2=0 and Q_3=0.005-0.0052 m^3/h, and

b) 15.7% at flow rates Q_2=0.03-0.0385 m^3/h and Q_3=0.0049-0.0053 m^3/h.

The effects of UFR types T10 and T20 manufactured by ARI from Jerusalem on water measuring accuracy are less than that of type T30.

For calibration discharges, foreseen by the Protocol, through the testing of class B flow meter with 20 mm rated diameter and discharge of Q_n=1,5 m^3/h, it has been established, that:

- in the case, when consumption time was shorter than the time the meter was calibrated for, at discharges of , the range of the meter measuring error exceeded the range of permitted errors,
- the biggest errors occur at Q_{min} - for example, at discharge lasting for 0.5 minute, the error may be even 32.1% (for water meter reading accuracy of 2.5 centilitres), or even 50.9% (for water meter reading accuracy of 1 decilitre), or even 277.4% (for water meter reading accuracy of 1 litre), and

- to provide that measuring errors of calibrated flows be lower than the permitted ones, the minimum time for measuring these flows is 5 minutes (for water meter reading accuracy of 2.5 centilitres), 9 minutes (for water meter reading accuracy of 1 decilitre), or 60 minutes (for water meter reading accuracy of 1 litre).

Since it concerns 95% of water consumption measurement, such testings are necessary for all types of water meters used in the supply networks of this country.

Author details

Dr. Lajos Hovany*

Address all correspondence to: hovanyl@gf.uns.ac.rs

Faculty of Civil Engineering Subotica, Republic of Serbia

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