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Research Article

How does ageing of customer water meters effect the accuracy?

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ABSTRACT

Apparent losses and real losses are two main components of water losses in water supply systems (WSSs). Apparent losses are caused by water meter inaccuracies, illegal consumption, and data handling errors whereas real losses are associated with leakage, pipe bursts and overflow from storage tanks. In well managed WSSs, apparent losses mainly result from inaccuracies of water meters. Performance of water meters is affected from many factors such as meter type, class, size and age, installation, and water consumption profile.

In this study, new and used multi-jet type water meters, which is one of the most widely installed water meter type, were tested under different flow rates in a laboratory setup for performance evaluation. Starting flow rates and metering errors of new and used multi-jet water meters under varying flow rates were tested. Average starting flow rate for the new multi-jet (MJ-N) water meters is determined as 7.02 l/h whereas the multi-jet water meters with an age of more than 9 years (MJ-3) old have the highest starting flow rate with an average value of 40.18 l/h. Meter degradation for average starting flow rates shows an almost linear trend. All tested water meters tend to make more measurement errors at lower flow rates. As measurement errors for ageing meters (MJ-2 and MJ-3) are similar at medium and high flow rates, ageing of meters cannot be described by linear degradation. This study showed that ageing and water consumption profiles have a great impact on water meter performance. An evaluation on ageing effects on the accuracy of water meters is provided in this study.

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INTRODUCTION

Managing water losses in water supply systems (WSSs) is an important issue for sustainable management of water resources. Water losses are defined as the difference between system input volume of water and authorized consumption [1]. Water losses have two main components, so-called real and apparent losses. Real losses result from the leakage on distribution pipes and on service connections, and storage tanks while the apparent losses are associated with metering and data handling errors, and illegal consumption [2-5]. Reducing water losses is a key for sustainable management of WDSs. International Water Association (IWA) developed a standard water balance concept (Table 1) for better understanding of water losses. Real losses are the sum of water physically lost whereas apparent losses represent the

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amount of water used but not paid for [6]. Reduction in the volume of apparent losses plays an important role in increasing revenue of water utility.

Errors resulting from the inaccuracies of water meters are the main reason of apparent losses in well-managed WDSs [7]. Metering errors are resulted from many factors such as class, size and type of water meter, meter wear and tear, installation, maintenance and calibration of meters, water demand profile and water quality [8].

Different types of water meters are available depending on the measuring mechanism. Water meters perform measurements according to mechanical, electromagnetic, or ultrasonic measurement principles. In water meters with mechanical measuring mechanism, flow is measured as a result of the movement of a piston or an impeller by the water passing through the meter. In electromagnetic and ultrasonic water meters, flow is measured by electromagnetic measurement principle or ultrasonic waves [9]. Mechanical type water meters, which are divided in two types based on measurement mechanism as volumetric and velocity type, are the most widely used water meters [10]. The most widely used water meters for metering domestic water consumption are multi-jet type water meters which are velocity type water meters [8].

Unauthorized consumption of water might result from income status, legal limitations, socio-cultural status that can be managed with control and legal restrictions. Apparent losses caused by metering errors, which constitute an important part of apparent losses, are associated with type, classification, diameter, and age of water meters [7, 9, 10, 12, 13].

The metrological classification and technical requirements of water meters are specified by the *"Water meters for cold potable water and hot water – Part 1: metrological and technical requirements"*, ISO 4064-1 standard [14]. An error curve is defined by using the minimum (Q_1), transitional (Q_2), permanent (Q_3), and overload (Q_4) flow rates [15]. While the minimum flow rate refers to the flow at which the water meter starts operating within the maximum permissible errors (MPEs), overload flow rate refers to the highest flow rate measured for a short time within the MPEs of the water meter. Permanent flow rate is the highest flow rate at which the water meter starts to measure within the MPEs within the operating conditions. Transitional flow rate divides the flow rate passing through the meter into the upper and lower flow rate zones within the MPEs. Water meters are characterized by the ratio (R) of permanent flow rate to minimum flow rate that is used to define the accuracy range of water meters [14]. The accuracy class of the meters are defined according to metering performances of water meters. Accuracy class-1 and accuracy class-2 are the accuracy classes of water meters according to the ISO 4064-1 [14]. MPE for accuracy class-1 water meters at upper flow zones (Q_2<Q<Q_4) should not exceed the value of ±1% at water temperature between 0.1 and 30 ^{0}C and MPE for accuracy class-1 water meters should not exceed the value of ±3% at lower flow zones (Q_1<Q<Q_2). MPE at upper flow rates for accuracy class-2 water meters should not exceed the value of ±2% at 0.1 and 30 ^{0}C whereas MPE should not exceed the value of ±5% at lower flow zones [14].

Determination of apparent losses resulting from water meter inaccuracies is not only important for increasing revenue of water utilities but also important for a proper water balance that is used for water loss management strategies. Improper installation, tear and wear of moving parts of water meters over time, suspended solids in the water passing through the meter, accumulation in the meter, leaks and partial blockages in water cause measurement errors [10]. Varying flow rates depending on water consumption profiles of consumers affect water meter accuracy and meter accuracy is highly affected by ageing of water meters [7]. Determination of water meter accuracy is one of the most important steps for determination of water loss control strategies [11]. Furthermore, water meter accuracy is important for socially fair pricing of water [16]. Measurement errors of water meters can be positive or negative. In general, consumer water meters tend to make more measurement errors at low flow rates [17].

In this study, an experimental analysis in a weight calibrated laboratory setup was carried out to evaluate the ageing effects on metering accuracy of multi-jet water meters. As flow rates have a significant effect on water meter performance, measurement errors of tested water meters at different flow rates and average starting flow rates were

Table 1. The international standard water balance developed by IWA [11]

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Customer Meter Inaccuracies and Data Handling Errors	
		Real Losses	Leakage on Transmissions and Distribution Mains	
			Leakage on Service Connections up to Metering Point	
			Leakage and Overflows at Storage Tanks	

determined. This study aims to provide insights how ageing effects the performance of water meters at varying flow rates.

MATERIAL AND METHOD

Metering errors of multi-jet water meters were examined in a weight calibrated laboratory setup. The test setup, which consists of flow meter, rotameters, temperature sensors, electronic balance, water pumps, valves, mains etc., is depicted in Figure 1. [13]. The collection method [18] was applied to examine the measurement errors of tested water meters of which specifications were given in Table 2. A total of 43 multi-jet domestic water meters with dry chamber (same brand) was tested under varying flow rates, which were determined in a previous study [13]. Each water meter was tested at flow rates of 15 l/h, 30 l/h, 60 l/h, 120 l/h, 450 l/h, 750 l/h, 1200 l/h, 2500 l/h and 3125 l/h. Frequency distribution of consumed water at flow rates that water meters tested were obtained from a previous study [13]. Measurement errors of each tested water meter were determined by the collection method that water passing through the meter is collected in collection tanks and the amount of water determined by weighing [18]. Effects of water pressure on performance of water meters have also been reported in literature [15, 19] In this study, all water meters were tested at a water pressure value of around 4.5 bar that is very common for many water utilities.

Metering errors of each tested water meter were calculated by the following equation (1):

$$\varepsilon = \frac{V_m - V_a}{V_a}.100 \qquad (1)$$

where ε is the measurement error of water meter as percentage, V_m is measured volume of water by the meter, V_a is the actual volume of water. Starting flow rate of each meter that meter starts to metering was also determined.

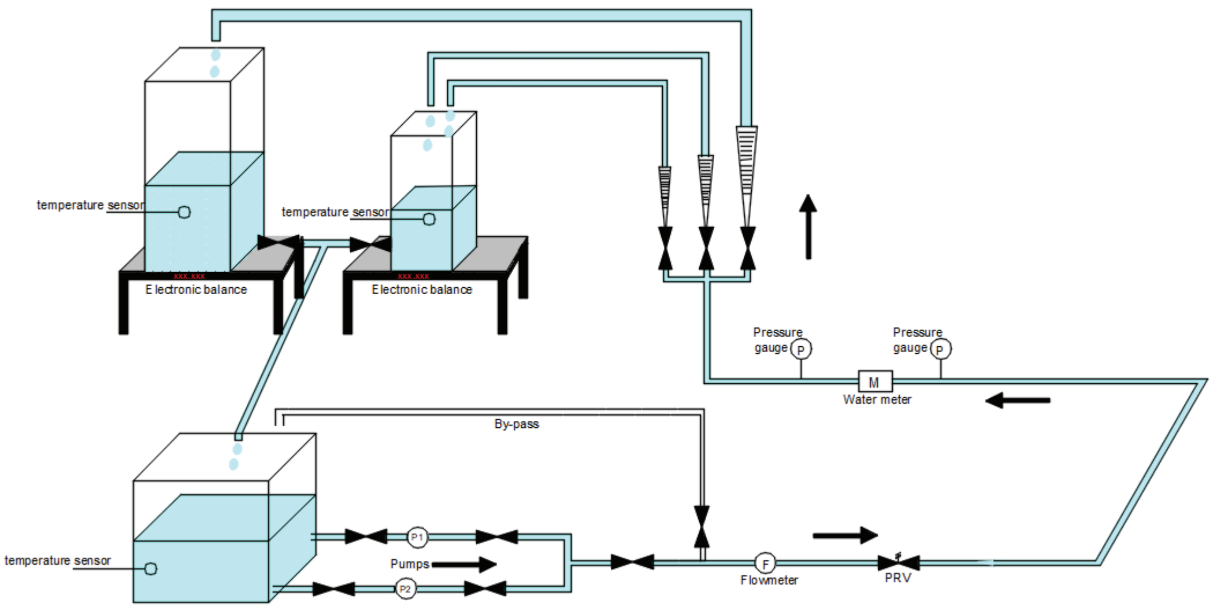

Figure 1. Laboratory setup for evaluation of water meter inaccuracies [13].

Table 2. Technical and metrological specifications of tested multi-jet water meters

Type	Technology	Age (years)	Metrological Class, R (Q_3/Q_1)	Standard	Q_1 (m^3/h)	Q_2 (m^3/h)	Q_3 (m^3/h)	Q_4 (m^3/h)	Length (mm)	Diameter (mm)	Number of meters
MJ-N*		New	100		0.025	0.040	2.5	3.125	190	20	10
MJ-1a		1-3	100		0.025	0.040	2.5	3.125	190	20	9
MJ-1b	Multi-jet	1-3	160	ISO4064: 2014	0,0156	0,025	2,5	3,125	190	20	5
MJ-2		5-8	100		0.025	0.040	2.5	3.125	190	20	9
MJ-3		9-15	80		0.03125	0.040	2.5	3.125	190	20	10

* MJ-N water meters were previously tested in a previous study [13].

RESULTS AND DISCUSSION

The multi-jet water meters are very commonly used by water utilities. The accuracy of water meters depends on many factors such as measurement technology, accuracy class, meter age etc. In this study, measurement errors at varying flow rates and starting flow rates of new and used multi-jet water meters with dry chamber were tested in a laboratory test setup. Starting flow rates of tested water meters are given in Figure 2. Ageing of water meters increases the average starting flow rates. The new multi-jet water meters (MJ-N) have the lowest starting flow rate with an average value of 7.02 l/h whereas the multi-jet water meters with an age of more than 9 years old (MJ-3) have the highest starting flow rate with a value of 40.18 l/h. Degradation of tested water meters can be described as almost linear for average starting flow rates.

The tested water meters MJ-1a and MJ-1b are almost at the same age. However, there is a slight difference between starting flow rates of MJ-1a and MJ-1b due to difference of metrological class of these meters. The water meters MJ-1a are accuracy class 2 meters with an R value of 100 while MJ-1b water meters are accuracy class 1 meters with an R value of 160.

Measurement errors at lower flow rates are higher for all tested water meters. Moreover, ageing affects the performance of water meters, which results in an increase in apparent losses. Maximum permissible errors (MPEs) for water meters with different accuracy classes are defined by specifications [14]. Measurement errors, MPEs and error curves of tested water meters are given in Figure 3. Measurement errors of water meters MJ-2 and MJ-3 are out of range of MPEs at all tested flow rates, which shows ageing effects on performance of water meters. As measurement errors of meters MJ-2 and MJ-3 are similar at medium and high flow rates, ageing of water meters cannot be described by a linear degradation. Measurement errors of water meter MJ-N are within the MPEs at flow rates higher than 30 l/h. The findings show that ageing and water consumption patterns have a considerable effect on performance of water meters. Experimental results and MPEs of tested water meters are summarized in Table 3.

Performance evaluation of water meters is crucial to control apparent losses, which are the total amount of water used but not paid for. Optimal selection and optimal replacement periods of water meters have a significant effect on reducing apparent losses and provide an increase in water utility revenue.

Selection of water meters should consider many parameters such as accuracy, water quality, size, and cost. Anyhow, water meters are generally selected based upon cost and basic measuring performance of the meters at certain flow rates given in standards. Water meters operate under different flow rates based on varying consumption patterns of end-users. All types of water meters, even if they are new,

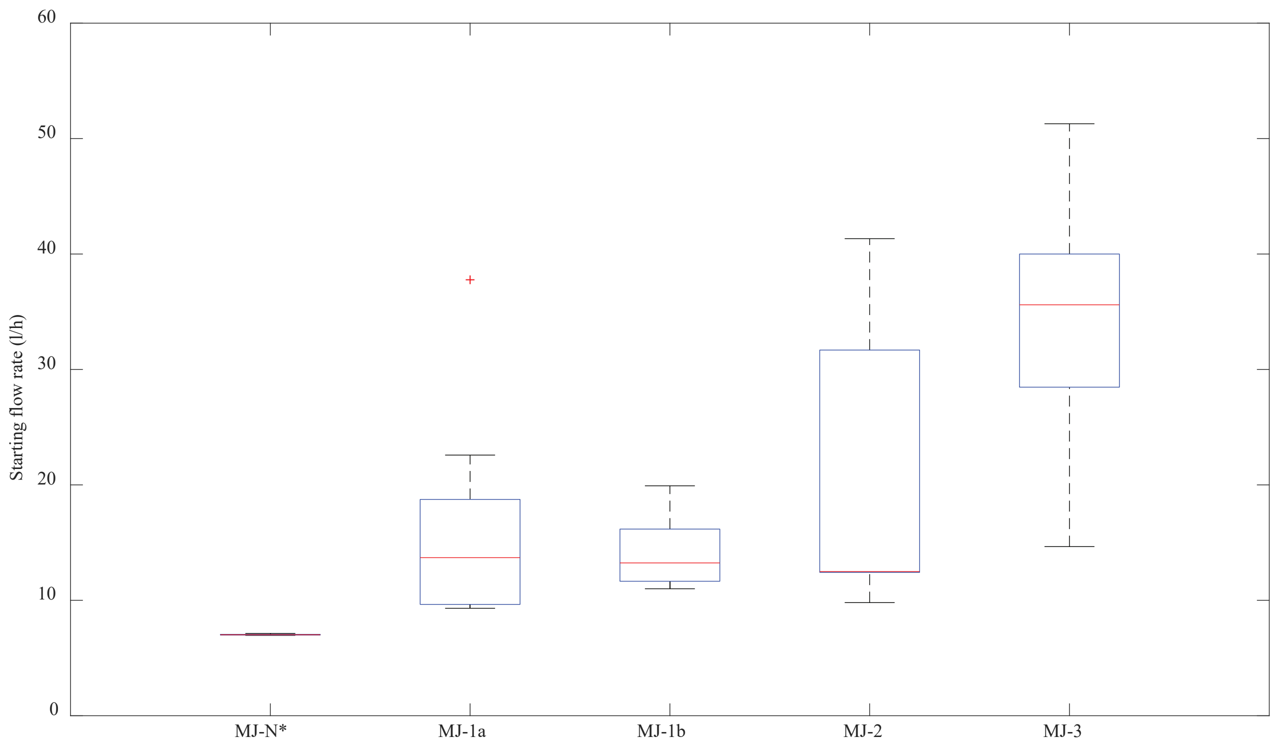

Figure 2. Box-plots showing starting flow rates of tested water meters (* MJ-N water meters were previously tested in a previous study [13].).

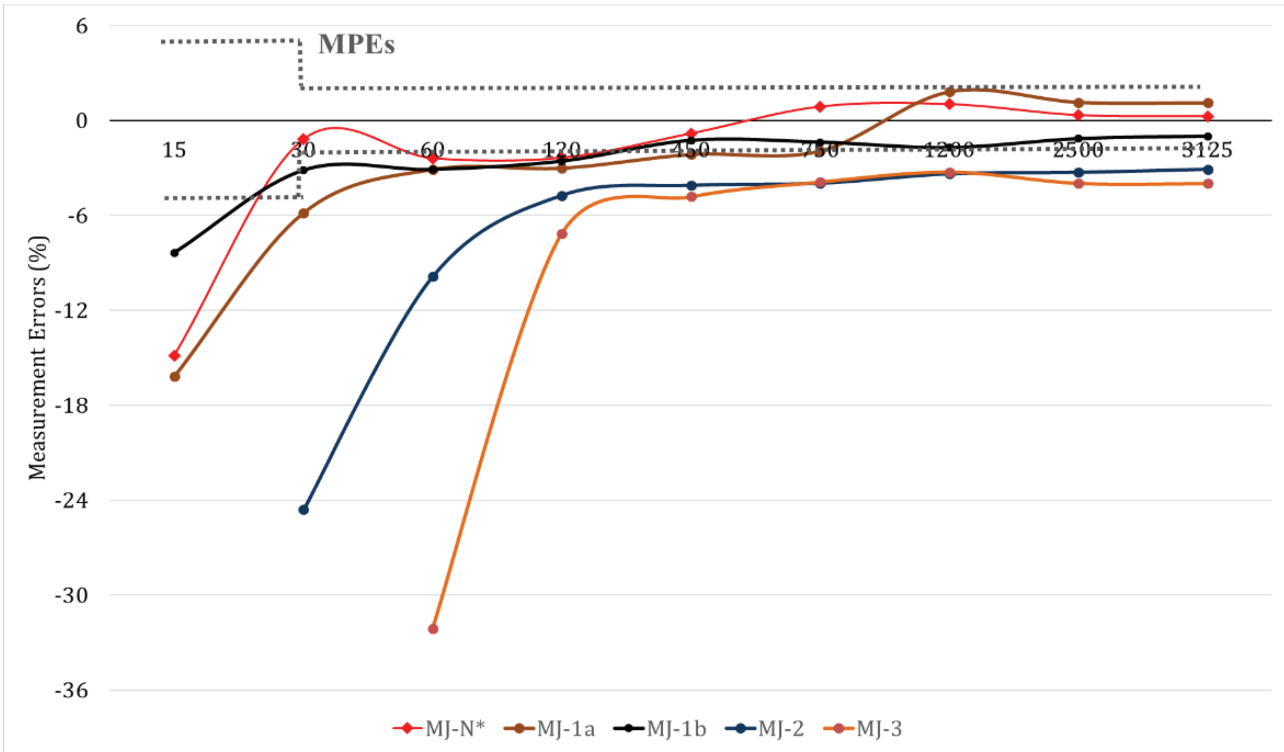

Figure 3. Error curves of tested multi-jet water meters at varying flow rates (* MJ-N water meters were previously tested in a previous study [13].).

have intrinsic errors. Therefore, consumption profiles of end-users should be considered for meter selection.

This study showed that water consumption profiles and ageing have a great effect on water meter performance. Water meters are generally replaced based on cost policy. However, optimal replacement period of meters should be determined considering degradation of meter performance as it will provide an increase in revenue of water utilities. On the other hand, determining meter accuracy is essential for calculating apparent losses and apparent losses are one of the main components of water losses. Calculation of apparent losses are also helpful to establish a proper standard water balance that is crucial to determine water loss management strategies. Performance evaluation method of water meters applied in this study provides a comprehensive understanding for controlling apparent losses and determining optimal replacement periods.

Table 3. Experimental results and MPEs of tested water meters

Flow rate (l/h)		15	30	60	120	450	750	1200	2500	3125
Water pressure (bar)						≈4.5				
Water meters	Ave. starting flow rate (l/h)				Average measurement errors (%)					
MJ-N*	7.02	-4.07	2.26	3.12	3.59	4.61	5.03	4.80	4.58	4.41
MJ-1a	16.24	-16.19	-5.85	-3.102	-3.021	-2.153	-1.937	1.804	1.137	1.106
MJ-2	21.42	N/A	-24.59	-9.87	-4.75	-4.12	-3.98	-3.39	-9.81	-9.78
MJ-3	40.18	N/A	N/A	-32.13	-7.16	-4.82	-3.89	-3.26	-3.97	-3.99
MPE, % (ISO 4064)		N/A	±5	±2	±2	±2	±2	±2	±2	±2
MJ-1b	14.13	-8.36	-3.16	-3.11	-2.59	-1.27	-1.39	-1.73	1.17	1.01
MPE, % (ISO 4064)		N/A	±3	±1	±1	±1	±1	±1	±1	±1

* Test results of MJ-N water meters were obtained from a previous study [13]

CONCLUSION

Management of water losses is a challenging task for water utilities. Controlling water losses in WDSs results in reduction of demand on water supply, cost, energy and chemicals for treatment. Determination of inaccuracies of water meters is crucial for water loss control strategies. Water meter inaccuracies are caused by many factors such as type, size and age of water meter, water demand profile, water quality etc. Apparent losses resulting from water meter inaccuracies can be controlled by implementing optimal selection and replacement period strategies. An increase in water utility revenue leading better services for consumers can be achieved by controlling apparent losses. Moreover, water meter inaccuracy is important for socially fair pricing.

This study showed that ageing and water consumption profiles have a significant effect on performance of water meters. Starting flow rates of tested water meters show a linear degradation. However, measurement errors of ageing water meters at medium and high flow rates cannot be described by linear trend. Weighted measurement errors considering frequency distribution of water meters for meter degradation models should be studied in further studies. Metering errors can be positive and/or negative. Measurement errors of new water meters tend to make negative errors at low flow rates whereas metering errors at medium and high flow rates are relatively smaller. According to the findings of this study, ageing meters tend to make negative errors at almost all flow rates, which results in an economic loss of water utilities.

Ageing of water meters can vary significantly based on many parameters such as water quality, water meter size, type, and brand. Optimal replacement periods of ageing water meters and measurement errors of different type of water meters should be studied for different water systems in further studies. Selection and optimal replacement periods of water meters considering metrological and technical specifications of water meters, and water consumption profiles can be helpful for management of apparent losses. Findings of this study cannot be extrapolated as water meter accuracy depends on many variables. However, this study provides an insight on measurement errors of ageing water meters.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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