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AWWA WATER SCIENCE

ORIGINAL RESEARCH

Accuracy of residential water meters in response to short, intermittent flows

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The purpose of this study was to measure the accuracy of residential water meters in response to short, intermittent flows. A gravimetric test bench was used as a standard to test 5/8″ × 3/4″ ultrasonic (US), electromagnetic (EM), nutating disc (ND), and oscillating piston (OP) meters. A programmable solenoid valve was used to create burst flow cycles. Three cycles of defined times were included in the study when the solenoid valve was open and closed and, subsequently, when water was flowing and not flowing—creating short, intermittent flows. Accuracies of water meters were tested at three flow rates: 4, 2, and 0.25 gpm. It was found that some of the US meters were affected by burst flows. EM meters were essentially unaffected by any burst flows. The accuracies of the ND and OP meters at the lowest flow tested were affected by burst flows.

KEYWORDS

burst, intermittent, residential, short, water meter

1 | INTRODUCTION

The purpose of this study was to measure the accuracy of residential water meters in response to burst flows. Burst flows are intermittent flows that can occur for a variety of reasons, like wetting a toothbrush or razor, using a nozzle-equipped garden hose, or using motion-activated faucets. Burst flows have short durations (a few seconds or less) and occur at flow rates typical of household appliances. No previous research has been conducted on burst flows, perhaps because of the low resolution of flow-monitoring technology. For example, flow-monitoring technology that is currently in use records the flow at a meter every 10 s. As the resolution of flow-monitoring technology increases, burst flows will become easier to detect and analyze. While an individual burst has a small volume, the cumulative volume of burst flows becomes significant over time.

The data for this study were collected at the Utah Water Research Laboratory at Utah State University in Logan using a gravimetric test bench as a standard for comparison. Forty-two meters of seven different models were tested (six meters for each model). Positive displacement (oscillating piston [OP] and nutating disc [ND]) and electronic (electromagnetic [EM] and ultrasonic [US]) meters were included in the study.

It should be understood that, realistically, a household setting will generally not see burst flows occurring in a repeated manner, such as those tested in the laboratory. For the purposes of laboratory testing, however, time-on and condensed time-off combinations were used. The reduced time off allowed for a controlled testing process and efficient data collection while still providing sufficient time gaps to remove any residual effect from one burst to another.

2 | LABORATORY TEST SETUP

Four meter types (i.e., OP, ND, EM, US) were used in this study. Among these were seven meter models, including six identical meters of each model. There were two models of ND meters, two models of OP meters, two models of US meters, and one EM meter model. Four manufacturers provided meters for the study.

TABLE 1 Accuracy by flow and meter model for continuous flows

	Meter model accuracy (%)						
Flow (gpm)	**US1**	**US2**	**EM1**	**ND1**	**ND2**	**OP1**	**OP2**
0.25	100.06	100.96	100.11	99.48	100.03	99.05	99.23
2	100.20	99.92	99.75	100.24	100.51	100.36	99.88
4	100.32	99.93	99.70	100.78	99.99	100.24	99.98
Average	100.19	100.27	99.85	100.16	100.18	99.88	99.70

Note. EM: electromagnetic; ND: nutating disc; OP: oscillating piston; US: ultrasonic.

The setup included a pressure-reducing valve to control the pressure in the system. Because water pressures in residences are generally between 20 and 80 psi, the pressure-reducing valve was set so the system pressure was 50 psi (±5 psi) for all tests.

For some of the tests, the system setup included a 2.1 gal thermal expansion tank downstream of the meters, simulating residences that have thermal expansion tanks (Thermal Expansion tank, PLT-5 Watts; Watts, North Andover, MA). One hundred feet of 1 in. cross-linked polyethylene (PEX) tubing also was included in the system downstream of the thermal expansion tank for some of the tests. PEX tubing is often used in residential systems as an alternative to copper tubing.

The solenoid valve was installed at the end of the test line. A software program was used to control the solenoid opening and closing cycles (Timer, Version 4.2.5; Hot Time Software, Ayr, Australia). The desired amount of time on and the desired amount of time off were programmed by the user. Three time combinations were used during the tests for data collection. They were (1) ½ s on, 3 s off; (2) 1 s on, 4 s off; (3) 1 s on, 3 s off.

Three flow rates of 4, 2, and 0.25 gpm were tested. The two smaller flow rates were selected because they are AWWA standard flows for 5/8″ × 3/4″ meters (AWWA, 2012). The 4 gpm flow was selected because it better represents higher flows that occur for individual appliances in a household setting than the AWWA standard of 15 gpm for maximum flow for 5/8″ × 3/4″ meters (AWWA, 2012). (Average bathtub flow rates of 4 gpm were considered to be the highest individual flow rate that could occur.) A minimum of 10 gal was collected during flow measurements using a gravimetric laboratory scale (Weigh-Tronix, BS-24X24 N; Avery Weigh-Tronix, Fairmont, MN).

Each meter had an electronic register with a resolution of 0.01 gal. Following the procedure outlined by Sumrak, Johnson, and Barfuss (2016), total uncertainty was calculated on the basis of random and systematic uncertainties. Only random error related to the weight tank scale was incorporated because all other random errors were assumed to be either negligible or too difficult to quantify. Systematic errors that were included were associated with the meter registers, the scale, and the thermometer. The meter with the highest recorded throughput was used to calculate the largest uncertainty. At 95% confidence level, the uncertainty of the registries was no greater than 0.69%.

Four setups were incorporated with the subject flow meters: (1) the thermal expansion tank ("Tank"; PLT-5 Watts, Watts, North Andover, MN) included, (2) the PEX tubing ("PEX") included, (3) both the thermal expansion tank and the PEX tubing ("Both") included, and (4) neither the thermal expansion tank nor the PEX tubing ("Neither") included.

Each meter was subjected to 36 tests (the meters were tested in two groups of 21 meters each). Each test had at least one variable that was different: either the flow rate (three options), the test setup (four options), or the time combination (three options). All possible combinations were studied.

3 | RESULTS AND ANALYSIS

3.1 | Accuracy by meter type for continuous flow tests

Before any burst flow tests were performed, continuous flow tests for the same flow rates were conducted on each of the subject meters to establish baseline accuracies. The initial average accuracies of the meters at the continuous flows are shown in Table 1.

Of all the meters tested in the continuous flow condition, only one US meter failed the 0.25 gpm test. All other meters had passing accuracies for the 0.25 and 2 gpm tests.

3.2 | Burst flow test results

Table 2 shows the average length of each test for each time combination and flow rate, as well as the average number of cycles required for the given flow rate and time combination.

TABLE 2 Average length of burst flow tests and average number of cycles required for tests

		Time combination (seconds on, seconds off)		
Flow (gpm)	**Units**	**0.5, 3**	**1, 4**	**1, 3**
0.25	Time (h:min)	4:34	3:09	2:30
	Cycles	4,694	2,264	2,243
2	Time (h:min)	0:33	0:25	0:20
	Cycles	558	296	303
4	Time (h:min)	0:16	0:12	0:10
	Cycles	273	149	149

TABLE 3 Accuracy by flow and meter model for burst flows

	Meter model accuracy (%)						
Flow (gpm)	**US1**	**US2**	**EM1**	**ND1**	**ND2**	**OP1**	**OP2**
0.25	97.30	99.06	99.68	90.52	91.36	88.64	89.98
2	97.74	99.56	99.84	100.14	100.65	99.53	99.43
4	88.49	99.36	99.94	100.56	100.34	100.27	99.95
Average	94.51	99.33	99.82	97.07	97.45	96.14	96.46

Note. EM: electromagnetic; ND: nutating disc; OP: oscillating piston; US: ultrasonic.

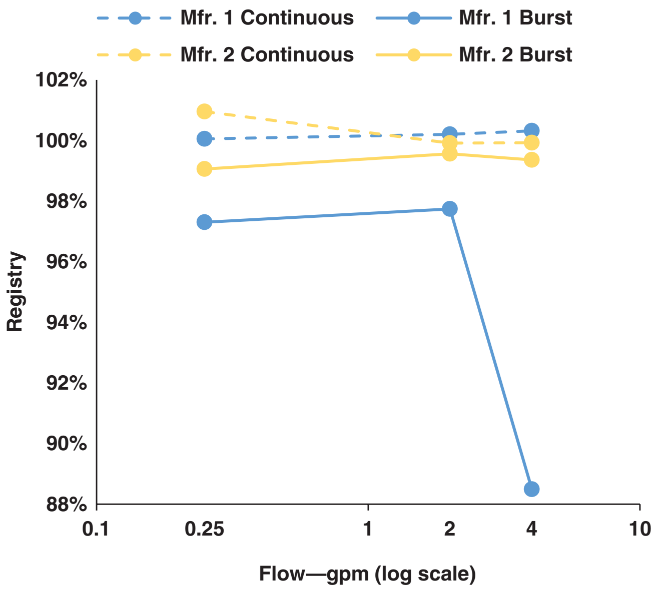

FIGURE 1 Comparison of continuous and burst accuracies of ultrasonic meters. Mfr.: manufacturer

3.3 | Accuracy by flow and meter model

Table 3 shows accuracies of meters by model. The values in Table 3 are averages of all the tests performed, including all test setups and time combinations.

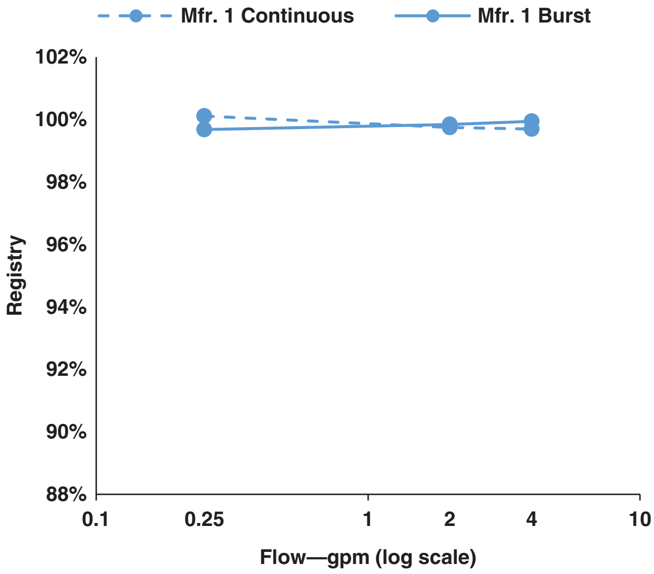

FIGURE 2 Comparison of continuous and burst accuracies of electromagnetic meters. Mfr.: manufacturer

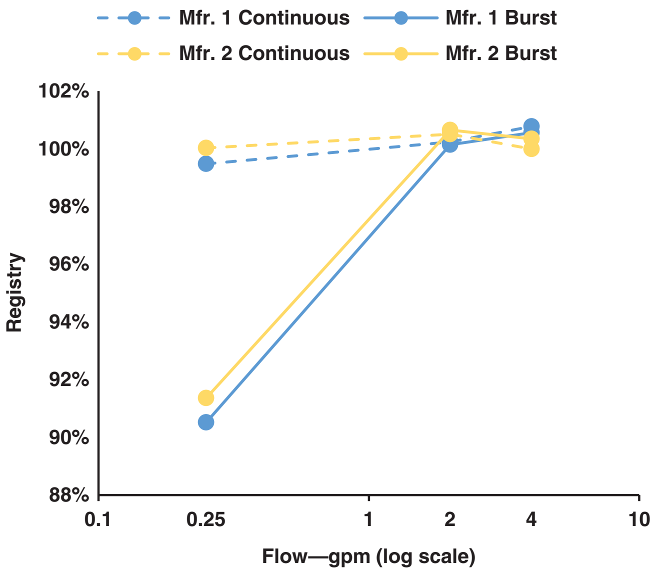

FIGURE 3 Comparison of continuous and burst accuracies of nutating disc meters. Mfr.: manufacturer

The varying meter types responded differently to the three flows. For example, the US meters by Manufacturer 1 reported the lowest accuracy at the 4 gpm flow. The ND and OP meters reported the lowest accuracies at the 0.25 gpm flow.

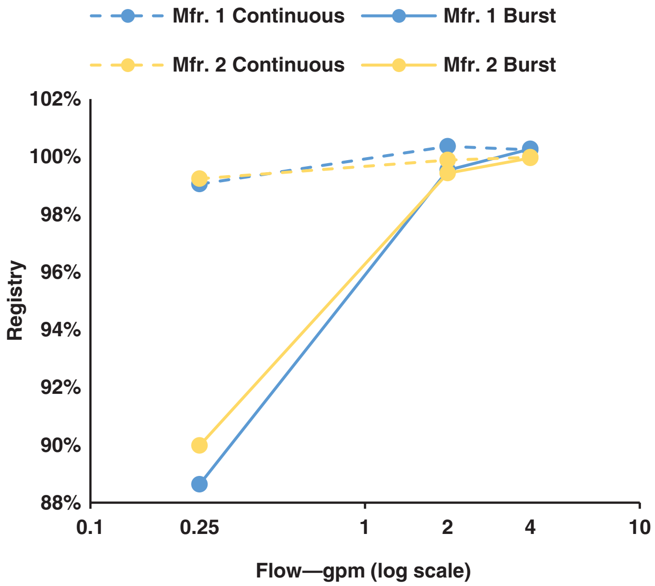

FIGURE 4 Comparison of continuous and burst accuracies of oscillating piston meters. Mfr.: manufacturer

TABLE 4 Accuracy by test setup and meter model

		Meter model accuracy (%)						
Test setup	**Flow (gpm)**	**US1**	**US2**	**EM1**	**ND1**	**ND2**	**OP1**	**OP2**
Neither	0.25	96.50	99.28	99.91	90.51	91.48	89.94	90.94
	2	98.41	99.71	99.97	100.08	100.57	98.94	98.83
	4	99.85	99.26	99.93	100.25	100.31	100.23	99.87
Tank	0.25	96.87	99.16	99.70	89.43	90.16	86.61	88.38
	2	86.84	99.73	100.02	100.25	100.76	98.94	98.93
	4	86.07	99.93	99.83	100.38	100.31	100.20	99.90
PEX	0.25	97.76	98.88	99.57	91.44	92.17	89.66	90.71
	2	106.75	99.50	99.60	99.99	100.68	100.25	100.07
	4	73.90	98.92	99.92	100.93	100.34	100.33	100.03
Both	0.25	98.07	98.93	99.53	90.68	91.62	88.33	89.90
	2	98.98	99.32	99.78	100.24	100.59	100.00	99.89
	4	94.14	99.32	100.10	100.70	100.41	100.30	100.02

Note. EM: electromagnetic; ND: nutating disc; OP: oscillating piston; PEX: cross-linked polyethylene; US: ultrasonic.

The largest standard deviation of 3.40% occurred within the US meter group. The ND meter model accuracies had a standard deviation of 0.27%, and the OP meter models had a standard deviation of 0.22%. No standard deviation was reported for the EM meters because only one EM model was tested. The results from the other meter types indicate standard deviations between meter models.

Figures 1–4 show the average results of the burst flow tests compared with the continuous flow tests.

3.4 | Accuracy by test setup and meter model

Table 4 shows the average accuracies when comparing test setup and meter model. The values presented in Table 4 are averages of all the tests performed, including all time combinations.

The US Manufacturer 1 meters had varied results based on test setup, while the US Manufacturer 2 meters had more consistent results. The ND and OP meters produced lower accuracies when only the thermal expansion tank was installed in the test setup compared with other test setups for the lowest flow. The

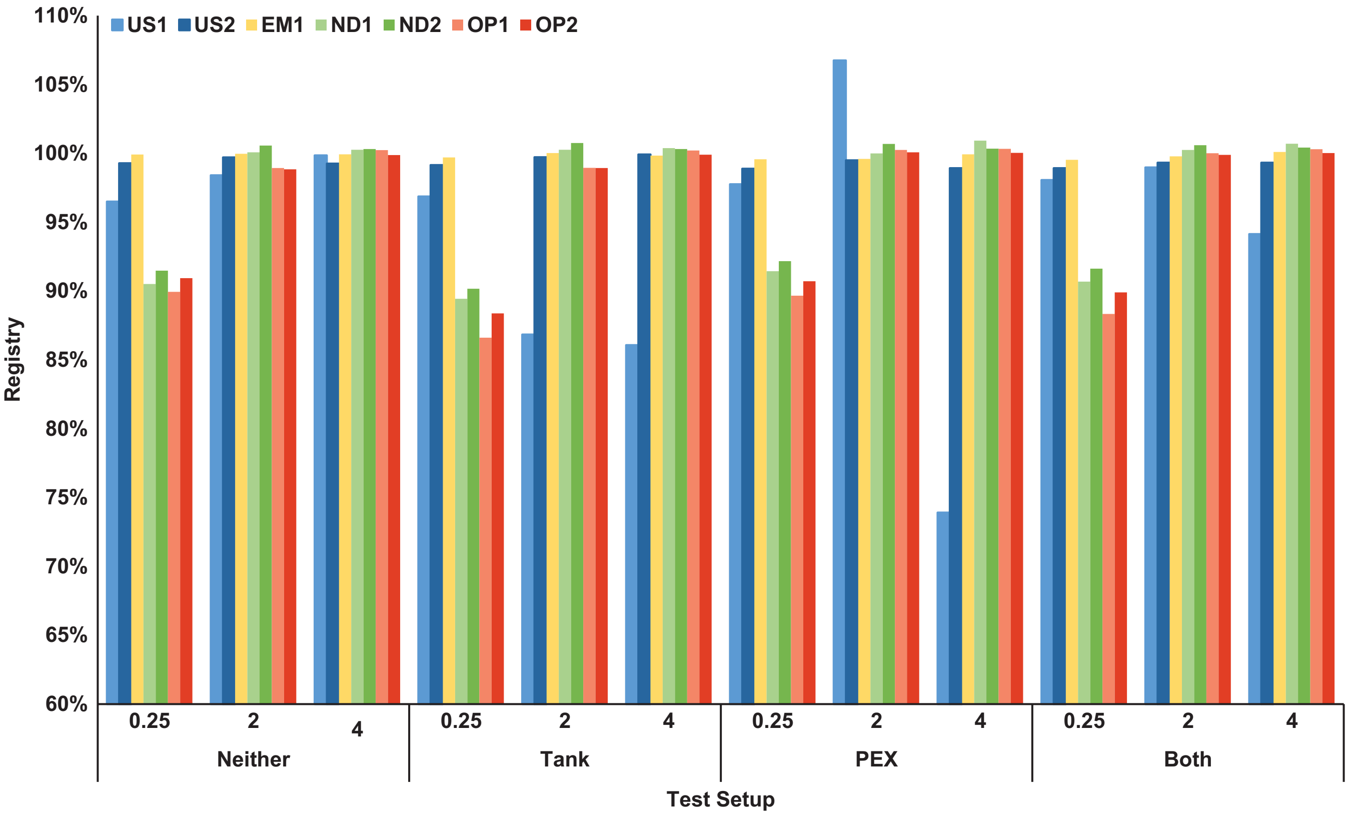

FIGURE 5 Burst flow results categorized by test setup. EM: electromagnetic; ND: nutating disc; OP: oscillating piston; PEX: cross-linked polyethylene; US: ultrasonic

TABLE 5 Accuracy by time combination and meter model

		Meter model accuracy (%)						
Test setup	**Flow (gpm)**	**US1**	**US2**	**EM1**	**ND1**	**ND2**	**OP1**	**OP2**
0.5 s on, 3 s off	0.25	99.31	101.45	99.36	89.95	89.40	84.62	86.70
	2	99.41	99.42	100.06	100.38	100.69	99.28	99.16
	4	100.92	99.02	99.99	100.69	100.38	100.24	99.85
1 s on, 4 s off	0.25	97.61	97.56	99.93	91.29	92.19	92.57	92.88
	2	99.74	99.57	100.04	100.28	100.68	99.78	99.65
	4	100.14	99.32	100.31	100.77	100.42	100.32	100.09
1 s on, 3 s off	0.25	94.98	98.18	99.74	90.30	92.49	88.72	90.36
	2	94.09	99.69	99.42	99.77	100.58	99.53	99.47
	4	64.42	99.73	99.53	100.23	100.23	100.24	99.93

Note. EM: electromagnetic; ND: nutating disc; OP: oscillating piston; US: ultrasonic.

EM meters exhibited virtually the same accuracy for each test setup. The results from Table 4 are shown in Figure 5.

3.5 | Accuracy by time combination and meter type

Table 5 shows the average accuracies when comparing time combination and meter model. The values presented in Table 5 are averages of all the tests performed, including all test setups. The results from Table 5 are shown in Figure 6.

3.6 | Analysis

It appears that US meters may frequently misread burst flows. One possible reason for these misreads may be that when a burst flow occurs between ultrasonic waves emitted by the transducers, it causes the meter to not collect the meter reading at all (or to record a very low registry). This case can be seen for the last data point for Manufacturer 1 of the US meter type as shown in Figure 7, where the meters registered an average of just over 20% of the actual throughput recorded.

Conversely, a second possible reason is that an ultrasonic wave generated by the transducers may occur when a burst flow is occurring but will not record the absence of flow immediately before and after the burst flow occurred. Depending on the length of the burst flow and the meter's sampling rate (i.e., the rate at which ultrasonic waves are emitted), the meter could report a significantly higher flow than actually occurred. This scenario is not as likely to occur as the first because multiple burst flows in a short amount of time will not occur as often as a

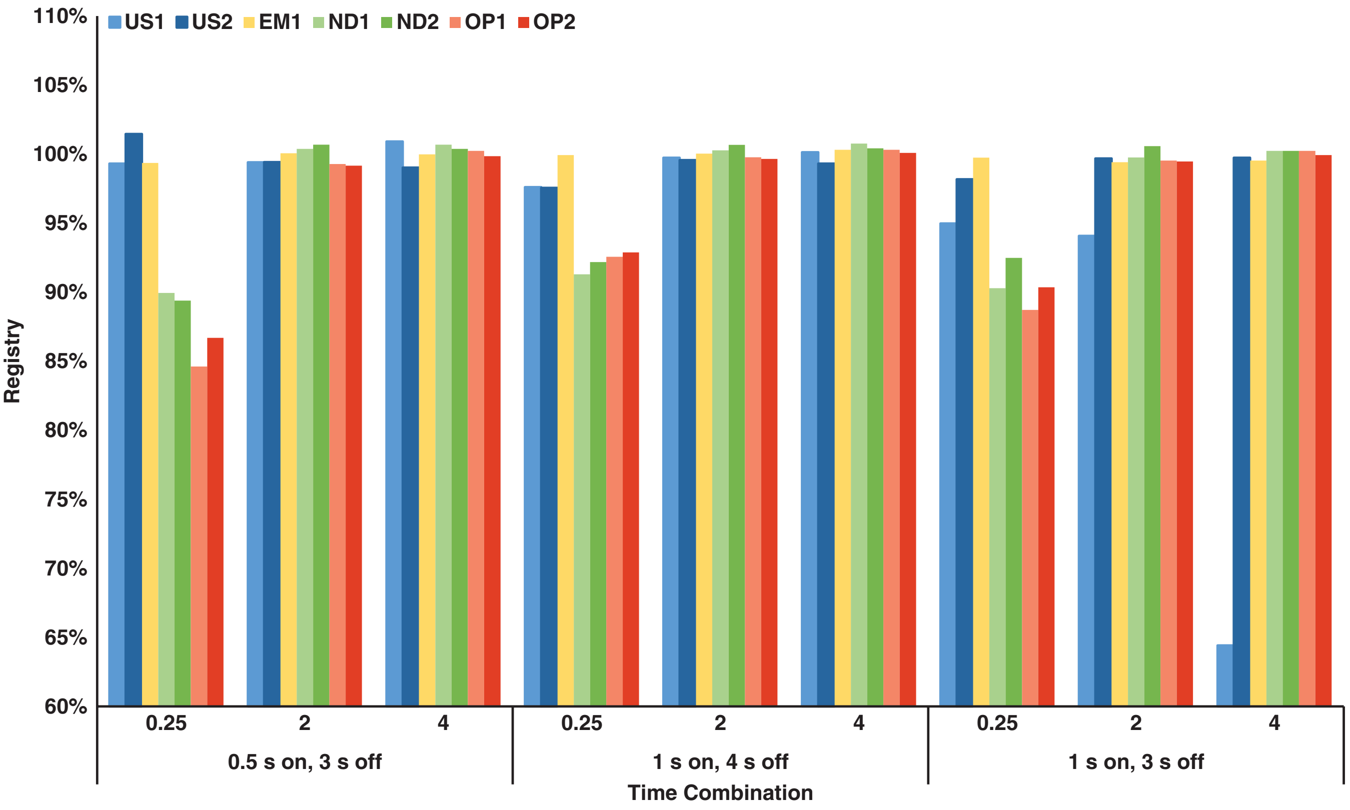

FIGURE 6 Burst flow results categorized by time combination. EM: electromagnetic; ND: nutating disc; OP: oscillating piston; US: ultrasonic

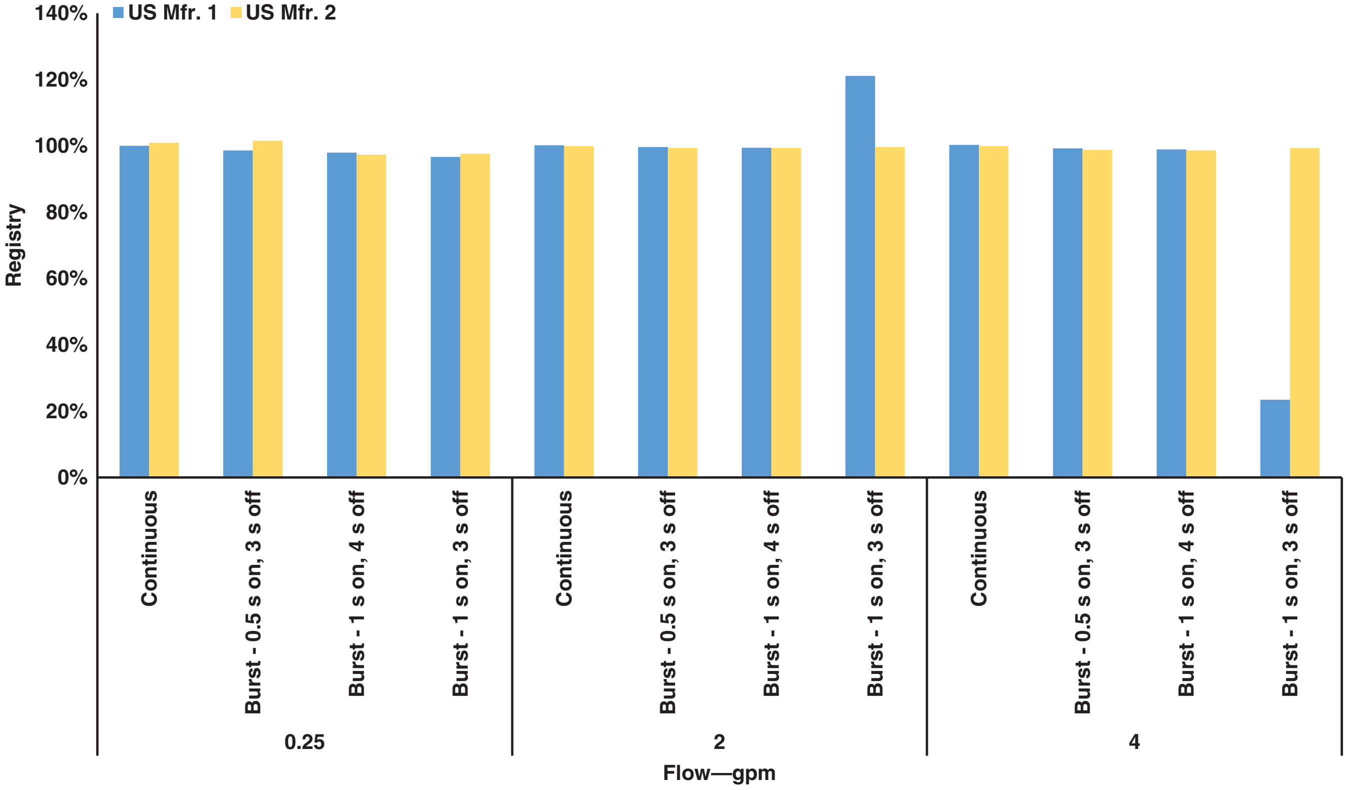

FIGURE 7 Registry of ultrasonic meters in continuous and burst (cross-linked polyethylene tubing) conditions. Mfr.: manufacturer; PEX: cross-linked polyethylene; US: ultrasonic

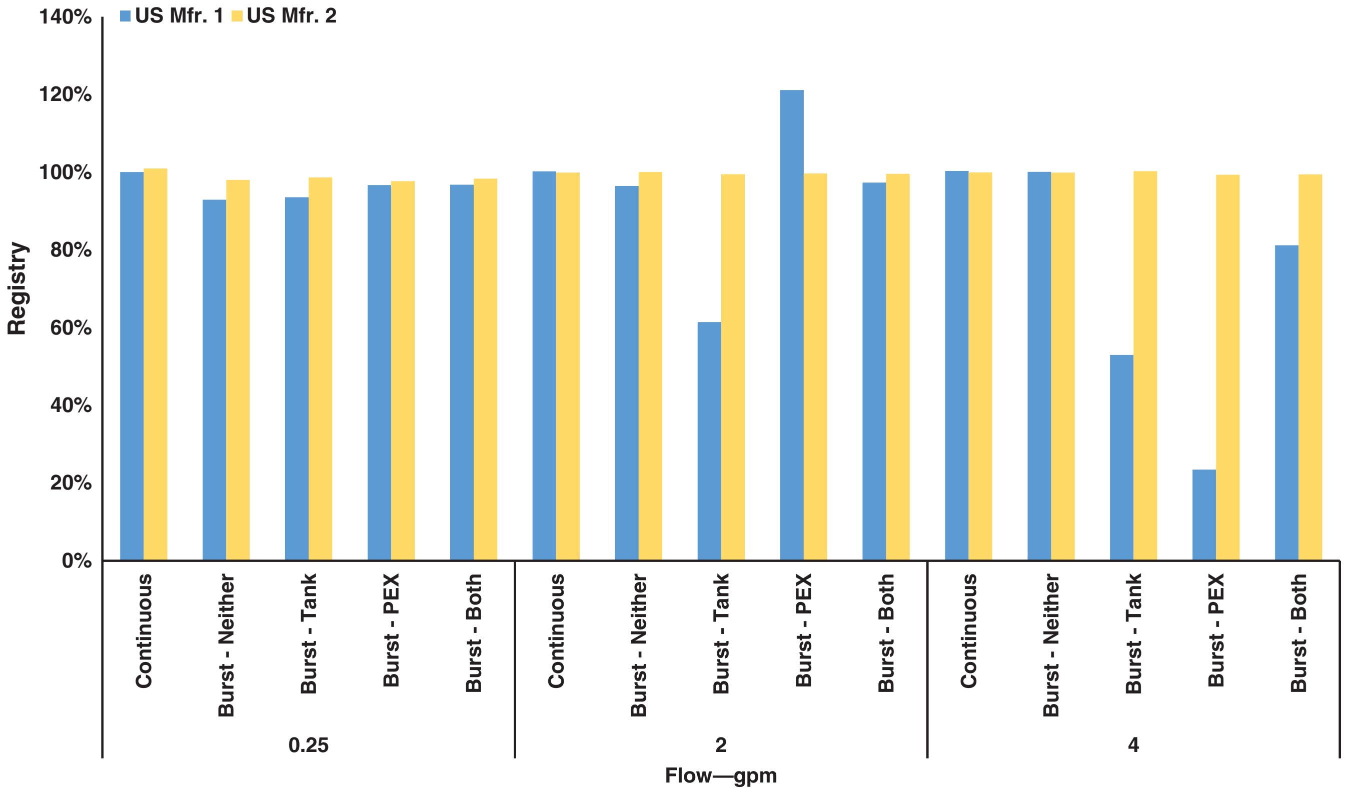

FIGURE 8 Registry of ultrasonic meters in continuous and burst (1 s on, 3 s off) conditions. Mfr.: manufacturer; PEX: cross-linked polyethylene; US: ultrasonic

single burst flow. However, this scenario was also seen in the test results for the US meters, as highlighted by the eighth data point of Manufacturer 1 as shown in Figure 7. A US meter's reading of the random occurrence of burst flows is hard to predict, but it can be seen from the results that burst flows will affect a US meter's accuracy.

Among the US meters, Manufacturer 1 had results that were much more varied than Manufacturer 2. For example, as shown in Figure 8, it can be seen that Manufacturer 1 reported average registries ranging from 23.47 to 121.14%. Under the same scenario, Manufacturer 2 reported average registries ranging from 97.69 to 100.96%.

Overall, the EM meters exhibited almost no change in accuracy (Figure 2). Because EM meters have no moving parts, they are generally able to register lower flows with greater accuracy. Also, EM meters do not record flow intermittently based on a sampling rate (the method described above as used by US meters), which further helps EM meters measure burst flows. Of all the EM meter data points collected for burst flows, the minimum registry recorded was 97.55%, and the maximum registry recorded was 102.38%. This tight range shows that, while burst flows did affect EM meters, the effects were minimal.

While all the ND and OP meter models had generally the same accuracy for the 2 and 4 gpm burst flows, they exhibited decreased accuracy for the 0.25 gpm burst flow (see Figure 3 and Figure 4). For continuous flow tests, a previous study showed the adverse effects of low flows on mechanical meters. “As flow rates become smaller and smaller, the bearing, friction and drag forces within the metering mechanism become proportionally larger” (Barfuss, Johnson, & Neilsen, 2011). Not only are those forces proportionally larger for low flows when water has already begun to flow, but the force required to overcome the inertia of a disc or a piston at rest is also thought to be proportionally larger and must be overcome to allow flow to begin. In a continuous flow, the force required to begin moving the mechanical parts of a meter must overcome static friction forces only once. However, every burst flow that occurs requires the repeated overcoming of static friction forces. As each test for this study included multiple bursts (Table 2), the negative effects caused by the disproportionality of low flow rates to static friction forces possibly compounded the meters’ decreased ability to correctly register the throughput.

The maximum registries for each of the two ND meters and each of the two OP meters were below 102%. The minimum readings for each of the mechanical meter types were between 68.51% (OP Manufacturer 1) and 78.40% (ND Manufacturer 1). It can be seen that, for burst flows, mechanical meters generally under-registered.

It is clear that both the PEX tubing and the thermal expansion tank had an effect on meters’ responses to burst flows. As seen in Table 4, when included in the test setup separately, the PEX tubing and the thermal expansion tank caused some of the meters to more grossly over- and under-register. However, when both components were included together, the meters were generally more accurate. Meters generally performed the best when neither component was included in the setup.

Similarly, the time combinations had varied effects on different meters. As stated previously, the purpose of a variety of time combinations was to allow multiple bursts to occur over a short amount of time, without allowing one single time combination to be accepted as a standard for testing burst flows.

4 | DISCUSSION

Although an individual burst flow has a small volume, multiple bursts add up over time. If they are not measured accurately, burst flows result in lost revenue for utilities and more water consumed than customers are aware of. Burst flows are common in daily use and are found in many scenarios, such as with kitchen faucets, garden hoses, or automated faucets in public restrooms (Chadwick, 2018).

A major limitation of this study was the small number of flows and time combinations used. Test flows were selected to represent ideal burst flows, although both larger and smaller flows could have been tested. Any number of time combinations also could have been selected.

It is the recommendation of the authors to conduct further research concerning burst flows with higher and lower flow rates, different time combinations, varied test pressures, and other metering types and models (including other meter sizes) to see whether those results are found to be consistent with the results shown in this study.

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