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Testing of Water Smart Meters Under Various Conditions

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Abstract. The accuracy Smart water meters are being widely used across developed and developing countries in order to avail accurate and updated billing for the consumers and provide more accurate data for the water companies to manage their water networks. The accuracy and reliability of these smart meters under different scenarios such as line pressures, existence of air bubbles in the water pipes, existence of sand particles and different water salinity and meter idle time; are extremely important for both consumers and suppliers. SASO and ME-KFUPM have worked together for the last two years to carry out rigorous tests according to recognized standards to investigate the accuracy of these meters under various conditions mentioned above. The results of these investigations have revealed interesting findings regarding the accuracy and reliability of both Ultrasound and electromagnetic smart meters across various pressure levels (0.5-2.5 bars), different flow rates (Q1 to Q3), and in measuring transient pressures and flow rates. Notably, when air bubbles were introduced into the flow stream, all meter types exhibited intriguing outcomes. These findings contribute to our understanding of the capabilities of these meter types in diverse scenarios.

1 Introduction

The accuracy and durability of smart water meters are crucial for effective water management, especially in environments where water quality is compromised by dissolved salts and suspended particles. Several studies have investigated the impact of water quality on water metering performance, highlighting issues such as sedimentation, scaling, and sensor degradation.

Research has shown that water containing high concentrations of salts and suspended particles can influence meter performance over time. Accumulation of sediments in mechanical and ultrasonic meters may lead to inaccuracies in flow measurement and increased maintenance needs (Arregui et al., 2018). Additionally, high salinity levels can contribute to corrosion of internal components, affecting long-term precision (Lee et al., 2020). Extended idle states in water meters can exacerbate measurement errors due to particle deposition and biofouling. Studies indicate that meters exposed to stagnant water for prolonged periods may experience drift in sensor calibration, leading to over- or under-reporting of consumption (van Zyl et al., 2017). The performance of smart meters, particularly those relying on ultrasonic or electromagnetic sensing, can deteriorate due to changes in internal flow dynamics after long idle phases (Ahmed et al., 2021). Modern smart meters incorporate self-cleaning mechanisms and advanced algorithms to compensate for environmental effects. However, their performance varies under different water conditions. Research comparing electromagnetic, ultrasonic, and mechanical meters suggests that non-contact technologies are more resilient to sedimentation but may still experience inaccuracies due to conductivity changes in high-salinity environments (Galeano et al., 2019).

In this work, we explore experimentally the effects of salt concentration, sand presence, non-operation (idle) duration, temperatures, pressures and flow rates on the accuracy of three commercial flow meters. The study emphasizes the importance of testing real scenarios on the accuracy of commercial flow meters before installation.

2 Methodology

A test loop was designed to simulate very closely the setup of water meters as they are installed in the field or as connected to consumers. Since the meters are tested one at a time, the actual distance between the meters is not important for the testing.
Figure 1 shows the setup of the system as it was installed in the laboratory. The main components of the loop include a 10-Hp pump which can deliver water flow with high pressures. The pump draws water from a one-cubic-meter reservoir (larger tank in Figure 1) and supplies to the main pipe loop through a PVC pipe network connected to the main Polyethylene black pipe of 100 mm diameter as typically used in water distribution systems. The water meters labelled as DN15, DN20 DN25, DN32, DN40 and DN50 of three supplier brands ('A', 'B', and 'C') were installed on the wall of the laboratory and were connected to the main pipe via polyethylene flexible pipes. The flowmeter labels indicate the pipe nominal diameter which translates to their flow rate capacity. The three commercial flowmeters were of different working principles; 'A' and 'B' utilized ultrasonic waves to measure the flow rates, while 'C' utilized electromagnetic waves to perform the same task. The installation of the water meters was performed as per the installation standards of the service provider. The meters' outlets were connected to the main Meter-Verification System (MVS). The outlets of all meters were connected to a manifold piping system (6 into 1) to minimize the contact with the metering tank (smaller tank in Figure 1). The metering tank was placed on a calibrated scale with an accuracy of 0.03%. This

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accuracy has been verified with SASO-certified calibration weights.

Fig. 1. System Set-up as installed in the Fluid Mechanics Laboratory – KFUPM.

The error in measurement for all meters was computed as follows:

$$\text{Percentage Error} = \frac{M-\rho V}{M} \qquad (1)$$

The experiment tested various factors that could affect flow meter accuracy. The density of water, which was measured with 1% accuracy, ranges from 998 kg/m³ at 20°C to 990 kg/m³ at 45°C. Adding salt between 2 and 12 g/kg leads to a density variation of ±1%, and the maximum error in mass measurement was determined to be ±1.3%.

For salt concentration effects, five different concentrations (180, 3000, 5670, 8738, and 27660 ppm) were tested. These concentrations, chosen for comparison between low and high extremes, were compared with the maximum salinity recorded by service provider's network (4200 ppm in the Eastern region). To test the effect of sand on flow meters, sand concentrations of 0.25%, 0.5%, and 1% were added to the water, as sand can be present in real systems after maintenance or pipe breaks.

Idle time effects were tested by leaving the flow meters non-operational for various durations, ranging from several hours to 8 months. These tests, conducted under a line pressure of 1.5 bars and medium flow rates, simulate idle periods seen in Saudi Arabia and situations where customers might not require water for extended periods. The effect of line pressure was also studied, with five different pressures (0, 0.5, 1, 1.5, and 2 bar) applied. Each pressure level was tested multiple times, and the cumulative errors for each flow meter were recorded.

The inclusion of air in the flow stream was tested by injecting controlled amounts of air upstream into the flow meters. The gas percentage in the mixture is critical, and the Gas Void Fraction (GVF) helps determine the flow regime. A GVF less than 3-5% results in a dispersed bubbly flow, and the flow pattern is primarily influenced by the flow rates, angle, fluid properties, and conduit diameter, rather than surface roughness.

$$GVF = \frac{\text{Flowrate of air}}{\text{Flowrate of air + Flowrate of water}} \qquad (2)$$

Lastly, Temperature effects were tested from 20°C to 50°C, simulating varying environmental conditions. Flow rates were also examined at high, moderate, and low levels to assess meter performance. To test the different flowmeter operations under the different conditions, a pressure of 0.5 and 1.5 bar were chosen and the flow rate was ensured to be within Q_2 and Q_3 for each flowmeter according to the datasheets provided by the supplier. As per the datasheet, the acceptable cumulative error was reported to be ±6%. Any result outside of this range was deemed unacceptable.

3 Results and Discussion

3.1 Flowmeters operation with saline water

Figure 2 shows 'A' flowmeter errors at different salt concentrations. Most data fall within ±6% error, but all meters fail at the highest concentration. DN50 shows both positive and negative errors.

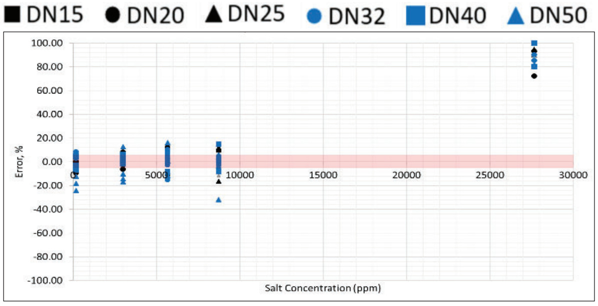

Fig. 2. Effect of salt concentration on all **'A' flowmeters**.

Figure 3 shows 'B' flowmeter errors. Most are within ±6% at low concentrations, but errors increase at moderate levels, and all fail at high concentrations. DN40 shows high errors at 3000 ppm, while DN20 and DN32 fail above 8738 ppm.

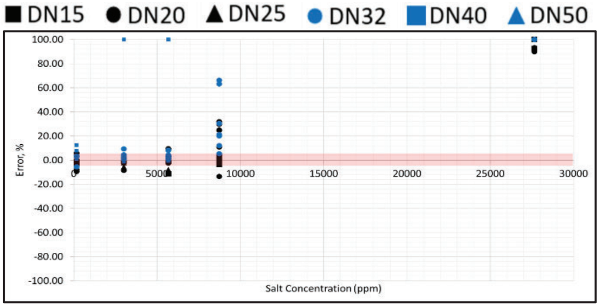

Fig. 3. Effect of salt concentration on all **'B' flowmeters**.

Figure 3 shows 'C' flowmeter errors. Most data fall within ±6%, but DN40 fails above 5670 ppm. All meters show errors at 5670 ppm but read accurately up to 27660 ppm.

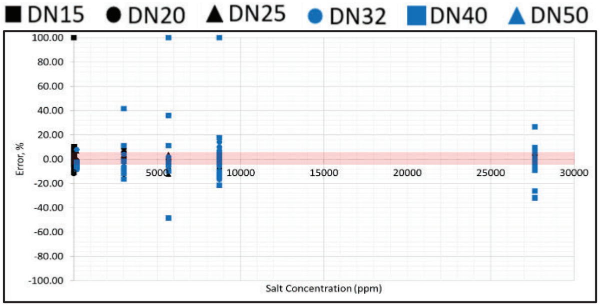

Fig. 4. Effect of salt concentration on all **'C' flowmeters**.

3.2 Flowmeters operation with water mixed with sand particles

Table 1 shows 'A' flowmeter errors. Most datapoints fall within the acceptable range, and all meters gave accurate readings at all sand concentrations.

Table 1: Average overall error at different sand concentrations for **'A' flowmeters**.

Sand conc. wt.%	Cumulative Error (%) of flowmeters DN-					
	15	20	25	32	40	50
0.25	-0.01	0.25	-0.01	0.25	-0.01	0.25
0.5	-0.01	0.5	-0.01	0.5	-0.01	0.5
1	0.00	1	0.00	1	0.00	1

Table 2 shows the error for different 'B' flowmeters, with cumulative errors of less than 1%, indicating acceptable accuracy.

Table 2: Average overall error at different sand concentrations for **'B' flowmeters**. NA indicates that no tests were done on the respective flowmeter.

Sand conc. wt.%	Cumulative Error (%) of flowmeters DN-					
	15	20	25	32	40	50
0.25	-0.02	0.00	-0.03	0.00	0.04	NA
0.5	-0.02	0.00	-0.01	0.01	0.03	NA
1	0.02	0.00	-0.02	0.02	0.90	NA

Table 3 shows the error for different 'C' flowmeters. Most data fall within the acceptable error, except for DN32, which performed poorly.

Table 3: Average overall error at different sand concentrations for **'C' flowmeters**. NA indicates that no tests were done on the respective flowmeter.

Sand conc. wt.%	Cumulative Error (%) of flowmeters DN-					
	15	20	25	32	40	50
0.25	0.01	0.03	-0.02	0.11	0.03	NA
0.5	-0.03	0.01	0.01	100	-0.02	NA
1	0.02	0.01	0.04	100	0.02	NA

Figure 5 shows DN40 has the highest fluctuations, with negative errors correcting positive ones. 'C' is the least reliable due to high fluctuations and DN32 failure.

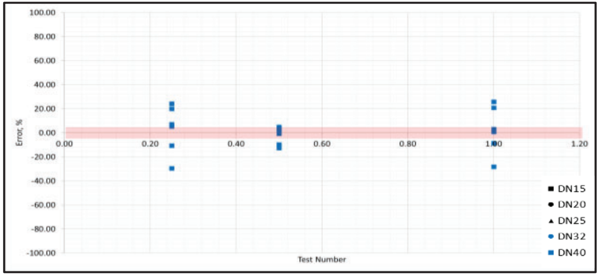

Fig. 5. Selected results showing the effect of sand concentration on **'C'-DN40 flowmeter**.

3.3 Flowmeters operation after different idle times

Figure 6.a shows cumulative errors for each flowmeter, and Figure 6.b shows steady-state error after 20 runs. All 'A' meters were acceptable, except DN50, which had consistent errors during idle times.

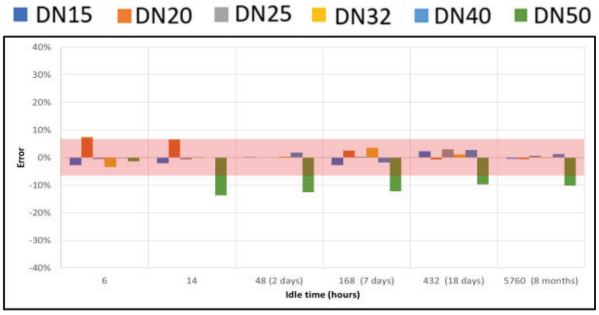

Fig. 6.a Error plot of all data collected under idle condition for **'A' flowmeters.**

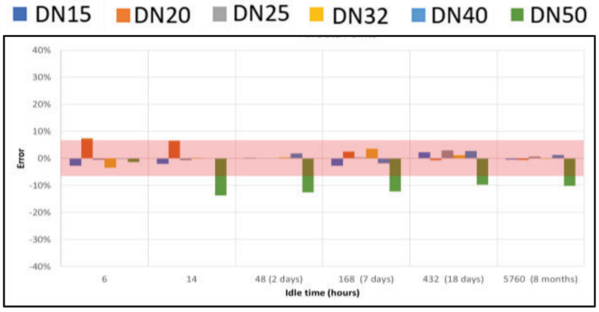

Fig. 6.b Error plot of last 4 data points collected under idle condition for **'A' flowmeters**.

Figure 7 shows the collected volume needed for accurate flow rate measurements, ranging up to 350 liters.

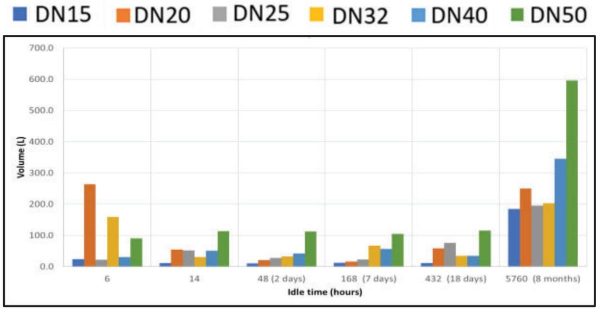

Fig. 7. Volume collected before final measurements were reported under idle condition for **'A' flowmeters**.

Figure 8 shows cumulative errors for 'B' flowmeters, and Figure 9 shows errors for the last 4 readings. DN15, 20, and 25 were acceptable, while DN32 and DN40 had errors at all idle times.

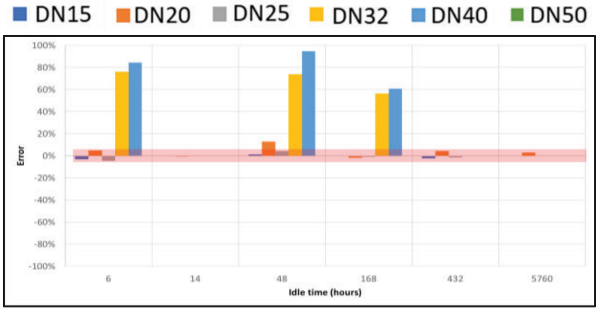

Fig. 8. Error plot of all data collected under idle condition for **'B' flowmeters.**

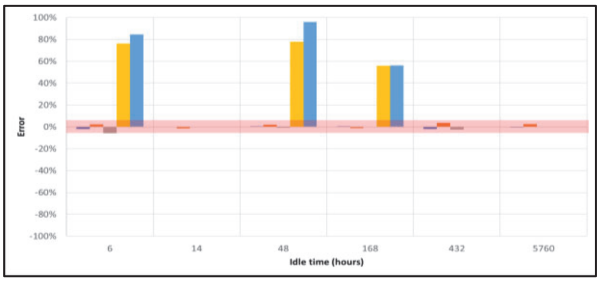

Fig. 9. Error plot of last 4 data points collected under idle condition for **'B' flowmeters**.

Figure 10 shows the collected volume needed for accurate flow rate measurements, ranging up to 80 liters.

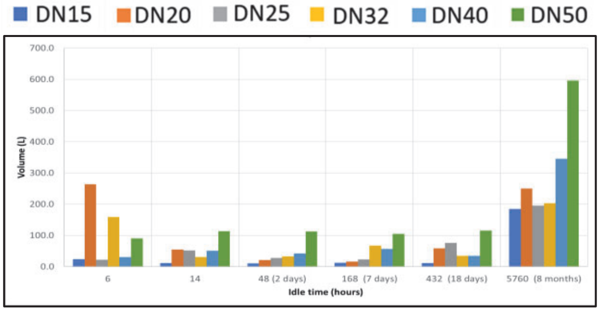

Fig. 10. Volume collected before final measurements were reported under idle condition for **'B' flowmeters**.

Figure 11 shows cumulative errors for 'C' flowmeters, and Figure 12 shows errors for the last 4 readings. Most flowmeters were acceptable, except DN40 at 7- and 18-day idle times, and DN32 at 7-day idle time after 300 liters.

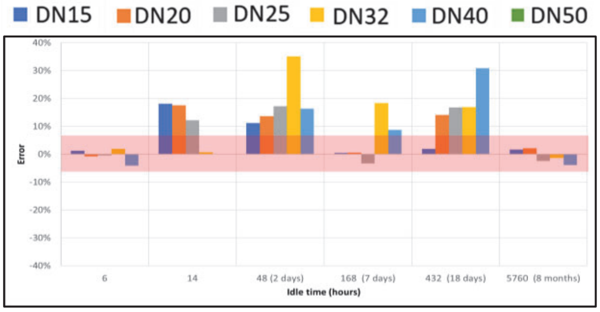

Fig. 11. Error plot of all data collected under idle condition for **'C' flowmeters.**

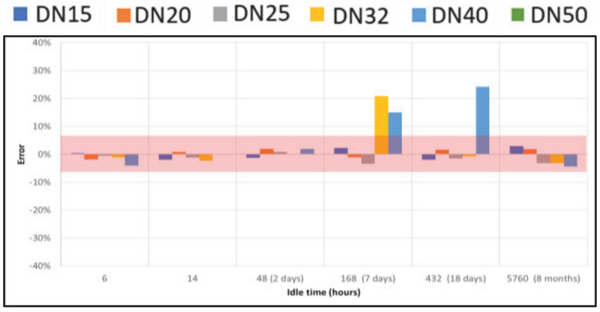

Fig. 12. Error plot of last 4 data points collected under idle condition for **'C' flowmeters**.

Figure 13 shows the collected volume required for final readings. The volume varies between flowmeters, with a maximum of around 212 liters.

■ DN15 ■ DN20 ■ DN25 ■ DN32 ■ DN40 ■ DN50

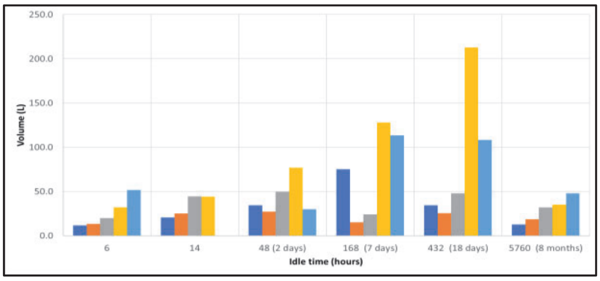

Fig. 13. Volume collected before final measurements were reported under idle condition for **'C' flowmeters**.

3.4 Flowmeters operation under different line pressures

Figure 14 shows the error at different line pressures for 'A' flowmeters. Most data points are within ±6%, with DN15 showing the highest average error.

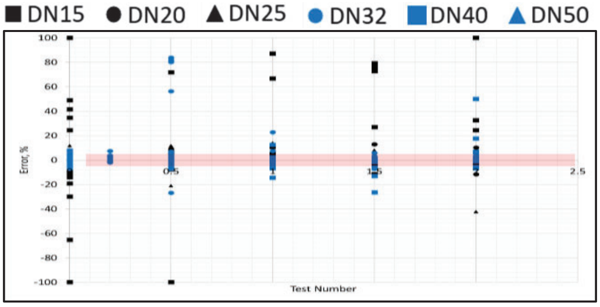

Fig. 14. Effect of pressure variation 0, 0.5, 1.5, 2 bar (gauge) on all **'A' flowmeters**.

Figures 15 and 16 show errors at various line pressures. Most points are within ±6%, with one 'B' flowmeter outperforming others. All flowmeters show excellent performance regardless of pressure.

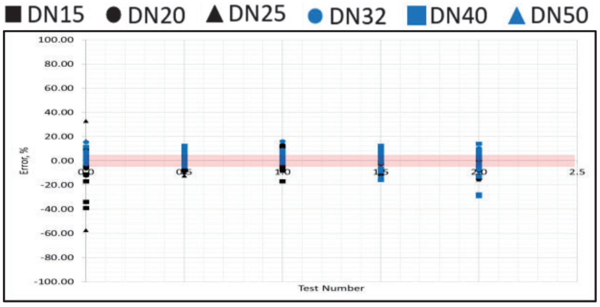

Fig. 15. Effect of pressure variation 0, 0.5, 1.5, 2 bar (gauge) on all **'B' flowmeters**.

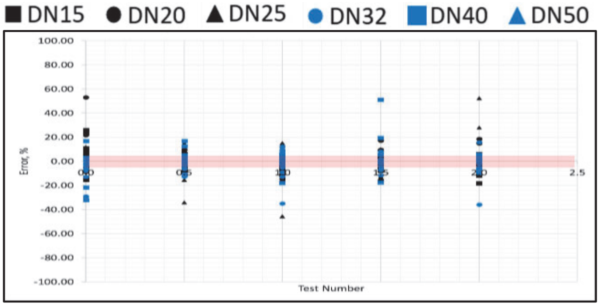

Fig. 16. Effect of pressure variation 0, 0.5, 1.5, 2 bar (gauge) on all **'C' flowmeters**.

3.5 Flowmeters operation under air bubble injection condition

Figure 17 shows GVF variation with percentage error for ‘A’ flowmeters. DN15 shows a +20% error at 4% GVF, DN20 a +80% error at 4.5% GVF, and DN25 a 45% error at 3.16% GVF. At GVF over 20%, the meters fail to record water.

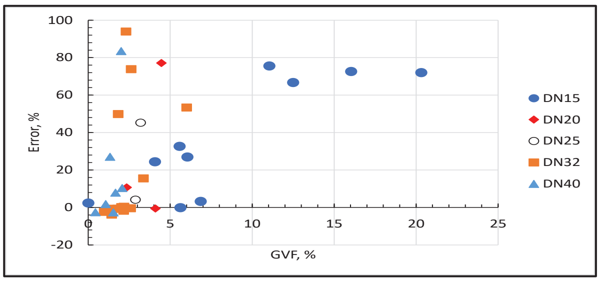

Fig. 17. Variation of GVF with % Error for all **‘A’ flowmeters**.

Figure 18 shows the GVF variation with error for ‘B’ flowmeters. They are sensitive to air bubbles, stopping at GVF values of 2-5%, with good accuracy for GVF <3%.

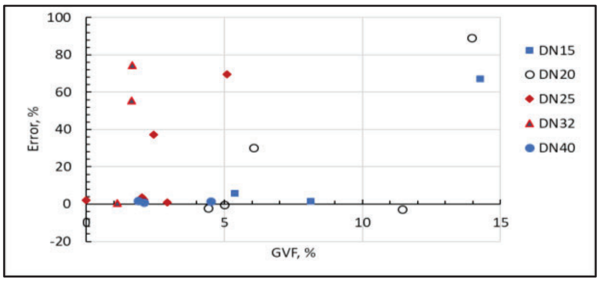

Fig. 18. Variation of GVF with % Error for all **‘B’ flowmeters**.

Figure 19 shows GVF variation with error for ‘C’ flowmeters. ‘C’ is less sensitive to air bubbles but often records more water than actual, with DN15 showing -21% error at 33% GVF and DN20 -22% at 23% GVF.

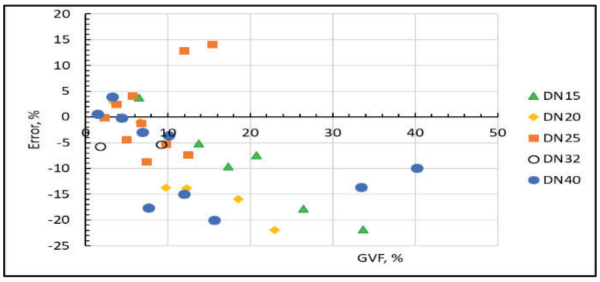

Fig. 19. Variation of GVF with % Error for all **‘C’ flowmeters**.

3.6 Flowmeters operation under different temperatures

A systematic analysis of temperature effects was not possible due to the lack of control mechanisms. However, natural temperature variations during testing provided sufficient data for evaluation. Temperature fluctuations, caused by viscous friction and heat transfer through convection and radiation, showed no clear correlation with measurement error.

‘A’ Meters: Tested between 20–37°C, with no significant impact on accuracy within the 5–50°C range (Figure 20).

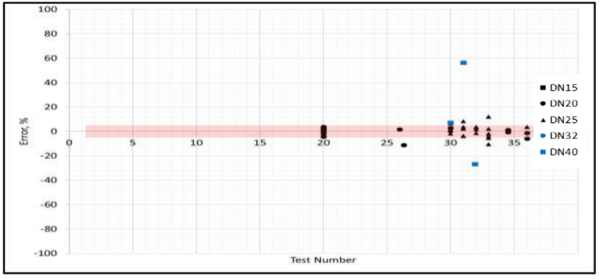

Fig. 20. Effect of Temperature variation on all **‘A’** meters

‘B’ Meters: Tested between 27–55°C, showing no noticeable effect on error within the 70°C manufacturer limit (Figure 21).

Fig. 21. Effect of Temperature variation on all **‘B’** meters

‘C’ Meters: Tested between 31–46°C, confirming stable performance within the 50°C specification (Figure 22).

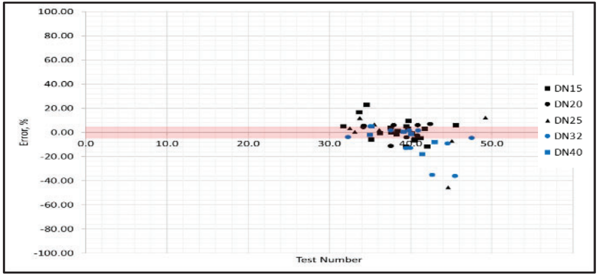

Fig. 22. Effect of Temperature variation on all **‘C’** meters

Overall, temperature variations within manufacturer-specified limits do not significantly affect meter accuracy.

3.7 Flowmeters operation under different flowrates

The effect of high flow rates on the water meters was tested for three types: ‘A’, ‘B’, and ‘C’. In most cases, the valve was fully open, with some instances at approximately 80% open. For all meters, most data points showed low errors (below ±2%), though a few data points for the DN15 and DN32 meters had larger errors. The DN50 meter’s data was entirely faulty. Flow rate is influenced by pressure, with higher pressures leading to higher flow rates. The meters were operated below their maximum flow rates to ensure accuracy, with most errors for high flow rates staying below ±6%, except in a few cases.

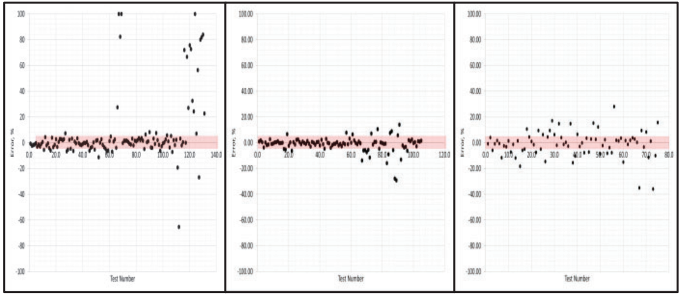

Fig. 23. Effect of high flow rate on 'A' , 'B' and 'C' meters

For low flow rates, the testing produced the best results, with flow rates selected based on the minimum allowable ranges for each meter. The flow rates were controlled using a ball valve upstream of the meters, simulating typical service provider's installation conditions. A needle valve would offer even more precise flow control. Despite slight variations in the control valve, all 'A', 'B', and 'C' meters provided acceptable measurements, confirming their accuracy at low flow rates.

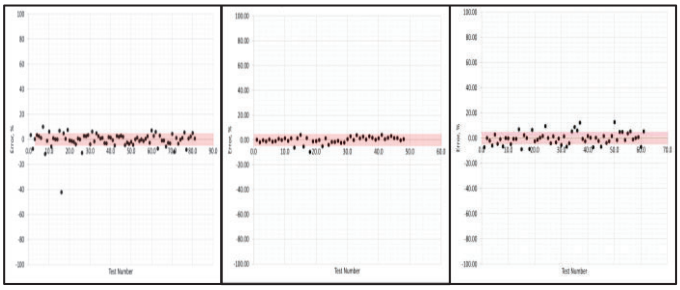

Fig. 24. Effect of low flow rate on 'A' , 'B' and 'C' meters

4 Conclusion

Tests on 16 smart meters (11 ultrasonic, 5 electromagnetic) examined salt concentration, sand particles, and idle durations.

1. **Salt Concentration**: Ultrasonic meters worked up to 6000 ppm but failed at 27000 ppm. 'B' DN32 and DN40 had errors at 9000 ppm. Electromagnetic meters read accurately at 3000, 9000, and 27000 ppm but showed errors at 6000 ppm.
2. **Sand Particles**: Sand (0.25–1%) did not affect accuracy but caused damage to valves and pumps due to erosion.
3. **Idle Duration**: Durations from 6 hours to 8 months had little impact. Electromagnetic meters required more time and water to read correctly, while ultrasonic meters were less affected.
4. **Line Pressure**: 'B' flowmeters performed best across all pressures, while 'A' had the highest cumulative error.
5. **Air Injection**: All meters worked well with GVF below 3%. At higher GVF, 'A' and 'B' showed positive errors, while 'C' showed negative errors and was least affected.
6. **Temperature**: Temperature variations within the manufacturer-specified limits (20–55°C) did not significantly affect the accuracy of 'A', 'B', or 'C' meters, with no clear correlation between temperature fluctuations and measurement error observed during testing.
7. **Flow Rate:** At high flow rates, most meters maintained low errors (below ±2%), except for DN15 and DN32, which had occasional larger errors. The DN50 meter produced entirely faulty data. Most high-flow errors remained below ±6%. At low flow rates, all meters provided accurate readings, confirming their reliability under typical operating conditions.

- It is recommended to include idle duration and air injection tests in standard evaluations. Ultrasonic meters can meter salty water up to 6000 ppm, while electromagnetic meters can handle up to 27000 ppm.
- Standard evaluations should include idle duration and air injection tests.
- Flow rate variations should be considered in performance assessments. While meters generally maintained accuracy, high flow rates increased error margins, particularly for DN15, DN32, and DN50 meters. More precise flow control (e.g., using needle valves) could improve measurement accuracy in low-flow conditions.

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