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Final Report

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Impact of disturbance on the Clamp on Ultrasonic Water Meters

AFMG Project A2102004

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Version History

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V1	Draft for comment	18/02/2022	John Awad	Baden Myers
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Summary

The technology employed in water metering has improved markedly in recent years. Previously, non-urban water meters used for trade were available with mechanical components. Now, many electronic meters are manufactured with ultrasonic or magnetic flow metrology technologies. One approach to adopting ultrasonic technology is where sensors can be clamped onto existing pipework without compromising the pipe, to perform a temporary or permanent water flow measurement. This method can be used to test the accuracy of a permanently installed conventional water meter.

Due to the increasing adoption of non-invasive ultrasonic water meters and their potential for in-field examination of water meter performance, evaluation of the impact of water flow disturbances on the measurement accuracy of non-invasive ultrasonic water meters is required. In this study, the error of measurement performance of five clamp on ultrasonic water meters was examined when the meters were attached various pipe types (PVC, HDPE and Steel) and sizes (200, 300 and 600 mm). Meter performance was also examined when exposed to three types of disturbance including the injection of air, sediment or a standard Type 3 flow 'swirl' (simulating typical disturbance caused by valves in test standards) into the full pipe flow. For this, meter performance was examined by comparing flow measurements with and without disturbance to determine any resulting shift in readings, termed the 'error shift'.

The results indicate that the error of measurement for the ultrasonic clamp on meters was influenced when the meters were moved from smaller to larger pipes, and when moving to different pipe materials, as evidenced by error shift results. When meters were moved from smaller to larger pipe sizes, the impacts were of medium concern (less than 5%). However, for a given pipe size, changing the pipe materials had a larger impact than changing pipe size. Changes in change in relative error of measurement with pipe material could be because the effect of pipe wall roughness, pipe wall thickness and/or coating material (for steel pipes).

The results also indicate that the error of measurement for the ultrasonic clamp on meters was influenced when the meters were exposed to the quarter plate disturbance (used in test standards to simulate typical flow disturbance conditions caused by valves) but the impact decreased as the upstream length between the disturbance and the meters increased, as evidenced by error shift results. When the quarter plate disturbances were applied at an upstream length of 2D between the disturbance and the meters, the impacts were considered to be of 'very large' concern. However, the impacts were considered to be of medium concern when the quarter plate disturbances were applied at an upstream length of 5D and 20D as the error shift was less than 5% and 3.5% in all cases, respectively.

The impacts of the presence of air at 1, 2.5 and 5 m^3/h flow rates were considered to be of medium concern (less than 5% in all cases) while the presence of air at higher flow rate (10 m^3/h equivalent to air/water volume ratio of ~6%) had a significant impact on the EUTs' performance (values were more than 50% in most cases). The impact of poor water quality (sediment) on the error of measurement performance of the water meters was considered to be of 'large' concern (with a 75th percentile of error shift of 8.3%).

Information about the typical error shift of ultrasonic clamp on meters is currently not available, and further research (or documentation of existing experience) is recommended to establish a required calibration interval for ultrasonic clamp on water meters. We note that a calibration interval of 12 months is used for all electromagnetic reference meters in the AFMG laboratory.

Although, the effect of pipe size, material and three types of disturbances on the clamp on ultrasonic water meters were tested in this project, other factors (e.g., those included in pattern approval testing such as the presence of swirl disturbance and exposure of the EUT to standard environmental conditions) was not considered. As such, it is recommended that clamp on ultrasonic meters selected for use as reference meters be pattern approved before use for in-situ meter verification as these other disturbance factors are considered during the pattern approval testing program.

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1. Introduction

The technology employed in water metering has improved markedly in recent years. Previously, non-urban water meters used for trade were available with mechanical components. Now, many electronic meters are manufactured with ultrasonic or magnetic flow metrology technologies. Ultrasonic flow meters use several underlying measurement approaches (Sanderson and Yeung, 2002). Growth in their use has been attributed to factors including improved battery technology, signal processing and waterproofing techniques (Prettyman et al., 2016). One approach to adopting ultrasonic technology is where sensors can be clamped onto existing pipework without compromising the pipe, to perform a water flow measurement.

Our research indicates that, given careful set-up, it is possible to use an ultrasonic meter to reliably check-test the accuracy of a permanently installed conventional water meter. This is particularly useful in Australia as an accuracy *validation* method because non-urban water meters are required to meet the accuracy parameters +/-5%. An ultrasonic meter could be used to check-test an installed flow meter while it is operational 'in-situ'. In the absence of an ultrasonic alternative to check-test accuracy, the only option is to use a check-meter which is approved to be accurate to within maximum permissible error ratings [MPE] +/-1.67%, and able to be installed in the flow line without disturbance. It is neither practical nor cost effective to undertake such a process.

Under the Metrological Assurance Framework 2 (MAF2, 2020) the Australian Government and the Australian states and territories agreed to take a more practical view of the in-situ accuracy checking requirements for compliant non-urban water meters. While instrument manufacturers have suggested the potential to check-test installed water meters by using non-invasive ultrasonic water meters, to date there has been no definitive examination of their performance. This research tested a range of ultrasonic meters under real world constraints such as flow disturbances, pipe size and composition.

In this study, the error of measurement performance of five clamp-on ultrasonic water meters was examined when the meters were attached to various pipe types (PVC, HDPE and Steel) and sizes (200, 300 and 600 mm). Meter performance was examined when exposed to three types of disturbance including the injection of air, sediment, or a standard Type 3 flow 'swirl' (simulating typical disturbance caused by valves in test standards) into the full pipe flow. The performance of each meter was examined by comparing flow measurements with and without disturbance to determine any resulting shift in readings, termed the 'error shift'.

2. Methods

2.1. Meters Examined

In this project, five clamp on ultrasonic water meters (A, B, C, D and E) were used to examine the effect of various pipe types (PVC, HDPE and steel) in sizes (200, 300 and 600 mm) on the meter performance.

2.2. Test Program and Error of Measurement Test Methods

An error of measurement determination on the supplied meters was conducted using a volumetric approach, comparing the flow measurement of each meter A to E compared to a calibrated reference meter. All testing was in accordance with the National Measurement Institute documents NMI M10-2 Section 6.3 at three flow velocities (0.75 m/s, 1.5 m/s and 3 m/s) with the test meters situated on 200 mm or 300 mm pipes, and at two flow velocities (0.75 m/s and 1.5 m/s) when the tested meters were situated on 600 mm pipe. The full range of testing is shown in **Table** 2. The meters were installed in accordance with the manufacturer's instructions with an upstream pipe length of 20 pipe diameters for 200 mm and 300 mm pipes (4 m and 6m, respectively) and 17.5 pipe diameters for 600 mm pipe (10.5 m). The test set-up is shown in **Figure 1**. The details of the pipes used in this project are provided in **Table 1**.

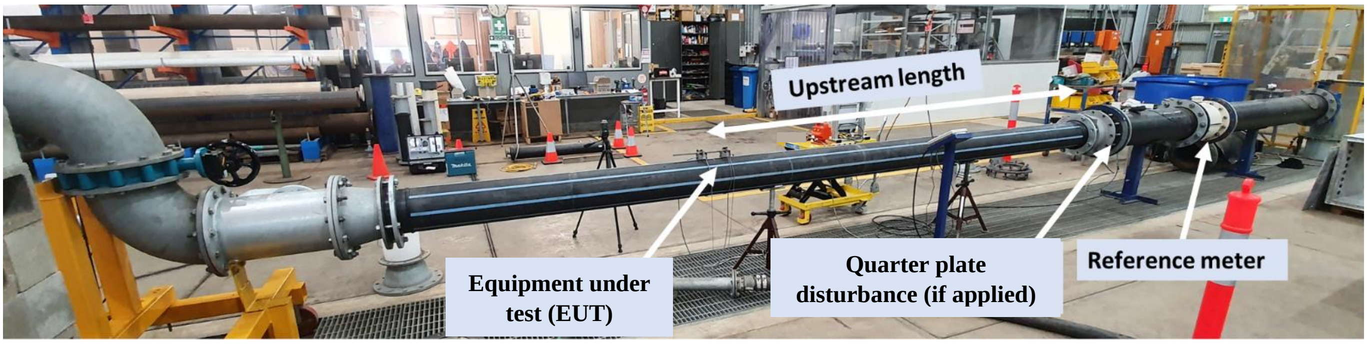

Figure 1 *- Test set-up used to examine the meter performance with and without disturbance (Quarter plate 'Type 3' disturbance)*

Table 1 *– Details of the pipes used in this project*

Reference	Pipe type	Outer diameter (mm)	Wall thickness (mm)
DN200	PVC	225.68	6.1
	Steel	219.7	8.58
	HDPE	251.5	24.4
DN300	PVC	316.08	9.1
	Steel	325.75	9.43
	HDPE	353.96	27.31
DN600	HDPE	630.25	16.43

2.3. Testing the impact of water quality – sediment, air and 'Type 3' flow disturbance

In this project, the meter performance was also examined when exposed to three types of disturbance including the injection of air, sediment or a standard Type 3 flow disturbance (simulating typical disturbance caused by valves or other throttling devices in test standards). For this, meter performance was examined by comparing flow measurements with and without disturbance to determine any resulting shift in readings, termed the 'error shift'.

The 'Type 3' flow disturbance test was conducted on the supplied meters at three flow velocities 0.75 m/s, 1.5 m/s and 3 m/s across the various pipe types (PVC, HDPE and steel) and the sizes (200, 300 and 600 mm). The NMI Type 3 Disturbance (quarter plate, **Figure 2**) was produced in accordance with NMI M10-2 Annex B for each pipe size. To examine the impact of proximity of the flow disturbance to the clamp on ultrasonic water meter performance, the error of measurement (and resulting error shift from the baseline no disturbance case) was determined when the test meters were exposed to a Type 3 disturbance situated 2D, 10D and 20D upstream of the meter installation as shown in **Figure 1**.

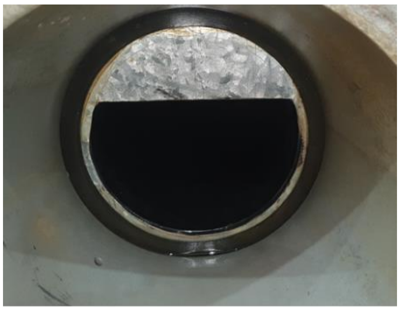

Figure 2 *- Quarter plate installed in 200 mm HDPE pipe*

***Table 2** – Summary of testing on non-invasive ultrasonic water meters*

Pipe size (mm)	Pipe material	Disturbance source	Upstream length (nD)	Flow rates (L/s)	Flow velocity (m/s)	EUT
Meter accuracy test						
200	HDPE, PVC & Steel	No disturbance	20D	23.6, 47.2, 94.4	0.75, 1.5, 3.0	A, B, C, D, E
300	HDPE, PVC & Steel			53.1, 106.2, 212.3		
600	HDPE		17.5D	212.3, 424.7	0.75, 1.5	A, B, D, E
Type 3 flow disturbance test						
200	HDPE, PVC & Steel	1/4 plate	2D	23.6, 47.2, 94.4	0.75, 1.5, 3.0	A, B, C, D, E
300	HDPE, PVC & Steel			53.1, 106.2, 212.3		
600	HDPE			212.3, 424.7	0.75, 1.5	A, B, D, E
200	HDPE, PVC & Steel		5D	23.6, 47.2, 94.4	0.75, 1.5, 3.0	A, B, C, D, E
300	HDPE, PVC & Steel			53.1, 106.2, 212.3		
600	HDPE			212.3, 424.7	0.75, 1.5	A, B, D, E
200	HDPE, PVC & Steel		20D	23.6, 47.2, 94.4	0.75, 1.5, 3.0	A, B, C, D, E
300	HDPE, PVC & Steel			53.1, 106.2, 212.3		
600	HDPE		17.5D	212.3, 424.7	0.75, 1.5	A, B, D, E
Water Quality Disturbance Test (based on NMI M10-2, Clause 6.10) [a]						
200	HDPE	No disturbance With particulate matter	20D	23.6, 47.2, 94.4	0.75, 1.5, 3.0	A, B, C, D, E
Presence of air Disturbance Test						
200	HDPE	No disturbance With air at five air flow rates (1, 2, 5, 10 and 20 m^3/h)	20D	47.2	1.5	A, B, C, D, E

[a] Particle class: Class 3; concentration: 3.00 g/L ± 0.3 g/L; Particle sizes: 30 to 35% between 75 µm and 300 µm, 30 to 35% between 300 µm and 600 µm and 30 to 35% between 600 µm and 2400 µm.

The water quality disturbance test was conducted on the supplied meters in accordance with NMI M10-2 Section 6.10 at three flow velocities 0.75 m/s, 1.5 m/s and 3 m/s for one pipe size and material (**200 mm HDPE)** as shown in **Table 2**. Note that the adopted particle size was Class 3, with a concentration of 3 g/L ± 0.3 g/L and a distribution as specified by NMI M10-2 Section 6.10 (30 to 35% between 75 µm and 300 µm, 30 to 35% between 300 µm and 600 µm and 30 to 35% between 600 µm and 2400 µm).

The effect of air on the error of measurement performance of each EUT was conducted at one flow velocity (1.5 m/s) and for one pipe size and material (**200 mm HDPE)** as shown in **Table 2**. Injection of air and sediment disturbance test set-up is shown in **Figure 3**. To further explore the impact of air in the flow line, error of measurement tests were undertaken with air at five air flow rates (1, 2.5, 5, 10 and 20 m^3/hr) corresponding to five different air water volume ratios (0.6, 1.5, 2.9, 5.9 and 11.8%).

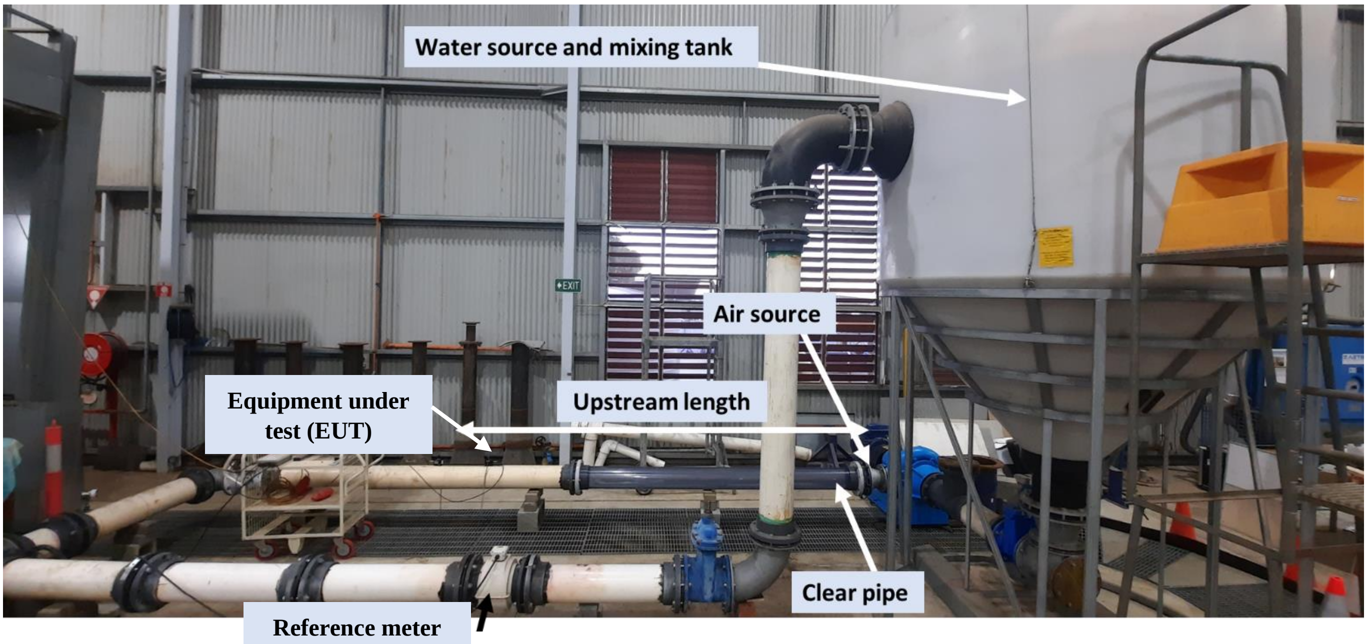

Figure 3 - Test set-up used to examine the meter performance when exposed to the injection of air and sediment disturbance.

2.4. Data Analysis

In this report, a maximum permissible error for the baseline (no disturbance/change) testing was adopted as 2.5% based on existing non-urban water meter pattern approval requirements (NMI M10-2). Note that there was no error correction attempted on the five meters examined – meter results were taken 'as is'. When comparing the impact of different pipe materials, pipe sizes or flow disturbances, the 'error shift' was calculated to compare the relative impact of the disturbance on the error of measurement.

The error shift was determined by subtracting the error of measurement with disturbance or change, from the error of measurement baseline (with no disturbance applied). The error shift is the same value that is used in pre- and post-disturbance testing for several pattern approval tests including disturbance testing (NMI M10-2 Section 6.8), endurance testing (NMI M10-2 Section 6.9) and water quality disturbance testing (NMI M10-2 Section 6.10). For this reason, the error shift compared to the no disturbance value was considered to be more informative about the impact of the disturbance than the raw error of measurement value (which is still reported in the Appendix).

Data was plotted for each meter comparing the original error of measurement values and the error shift due to applying disturbance or changing pipe size / material. To further explore the data, boxplots were produced indicating the median, 25th and 75th percentiles of data of tests at all flow rates.

For consistency in results and discussion, this report has adopted qualitative threshold terms to describe the maximum error shift resulting from applying change of pipe size, material or application of disturbance to all meters A to E as indicative of the performance of clamp on ultrasonic water meters. Where the maximum error shift was less than 2.5%, the change or disturbance to test conditions was considered a 'small' concern because 2.5% is the error of measurement threshold in national pattern approval standards for water meters (NMI M10). Error shift values from 2.5 to 5% were considered a medium concern, from 5% to 8% a large concern and from 8% to 20% a very large concern.

The impact of poor water quality (sediment) on the performance of the AFMG Reference meter was also examined by determining the error shift that occurred to the reference water meter flow rates with and without the presence of sediment in accordance with the procedure shown in **Table** 2. The result indicates that the presence of sediment had negligible effect on the AFMG Reference meter with average (± Standard deviation) error shift value of -0.4 ± 0.4%.

The presence of air impact on the AFMG Reference meter's performance was also examined by determining the error shift that occurred to the reference water meter flow rates with and without the presence of air at various air flow rates (i.e., 1, 2, 5, 10 and 20 m^3/s). Natural logarithm equations (**Figure 22**, Appendix) were used to model the changes in the meter performance (measured as the error shift) based on the air flow rates. Then, these equations have been used then to correct the results obtained from each EUT.

2.5. Test equipment

Details of all items of measuring equipment and test instruments used in the study are reported in **Table 3**.

***Table 3** – Listing of test equipment used in tests*

Parameter measured	Instrument/ equipment	Model number	Serial number	Calibration date Last	Calibration date Next	Used in test
Water volume	DN300 Reference Meter	ABB Magmaster	P/76869/3/1 AFMG W014	8/01/2021 & 19/12/2021	9/01/2022 & 20/12/2022	- Meter accuracy test - Quarter plate disturbance test
Water volume	DN200 Reference Meter	ABB Magmaster	P/77129/12/4 AFMG W013	16/06/2021	15/06/2022	- Water Quality Disturbance Test - Present of air Disturbance Test
Time	Stopwatch	Sports timer	AFMG W098	13/05/2021 & 10/11/2021	13/11/2021 & 13/05/2022	- Meter accuracy test - Quarter plate disturbance test
Time	Stopwatch		AFMG W069	13/05/2021	13/11/2021	- Water Quality Disturbance Test - Present of air Disturbance Test
Electric conductivity (EC)	EC meter	35 Series	W038	17/08/2021 & 16/12/2021	17/11/2021 & 18/03/2022	- All
Ambient Temperature/humidity	Temperature/Humidity sensor	HTC-1	W052	05/11/2020	06/11/2021	- Meter accuracy test - Quarter plate disturbance test
Ambient Temperature/humidity	Temperature/Humidity sensor	T-TEC 7-1 Data logger	C-6377 AFMG W096	5/11/2020	6/11/2021	- Water Quality Disturbance Test - Present of air Disturbance Test
Water pressure	700 kPa Crystal differential gauge	Crystal 100PSI XP2i	250734 AFMG P030	1/03/2021	2/03/2022	- Meter accuracy test - Quarter plate disturbance test
Water pressure	700 kPa Crystal differential gauge	Crystal 100PSI XP2i	924545 AFMG P031	18/01/2021	19/01/2022	- Water Quality Disturbance Test - Present of air Disturbance Test
Water temperature	Battery RTD with Display	WB Instruments DM650TM	AFMG W105	9/08/2021	10/08/2022	- Water Quality Disturbance Test - Present of air Disturbance Test
Water temperature	Battery RTD with Display	WB Instruments DM650TM	AFMG W106	9/08/2021	10/08/2022	- Meter accuracy test - Quarter plate disturbance test

3. Results

3.1. The effect of pipe size and materials on meter error of measurement

The impact of pipe size and material on the error of measurement performance of each EUT was assessed by examining the error shift of meters when tested on pipe made from PVC (**Figure 4**) and steel (**Figure 5**) with a nominal diameter of 200 mm and 300 mm. For HDPE, the error of measurement results of changing from 200 mm, 300 mm and 600 mm pipe are compared in **Figure 6**. **Table 4** summarises the ranges of error of measurement while **Table 5** shows the ranges of error shift values determined for all meters when tested in different pipe size. A plot representing the mean absolute error shift for all meters at each flow rate is presented in **Figure 7**. A boxplot illustrating the range of absolute error of measurement data for each pipe size and material is presented in **Figure 8.**

The results from comparing the effects of changing pipe size and material indicate that:

- Changing the pipe size had an impact on the error of measurement performance of the water meters. The impacts were considered to be of medium concern as the error shift when moving from smaller to larger pipe sizes was less than 5% in all cases (**Table 5**).
- For a given pipe size, changing the pipe materials had a larger impact than changing pipe size (e.g. compare error shift data in **Table 5** and **Table 6**). The highest error shift in this case was when moving from PVC to steel (10.8% for 200 mm pipe, 6.1% for 300 mm pipe).
- For PVC, changing from 200 mm to 300 mm pipe caused a relatively small error shift when compared to the other two materials at all three flow rates (**Figure 7**). Mean error appeared higher as flow rate increased (**Figure 7**), but this finding may be attributable to the results of one meter (Meter C, **Figure 4**).
- For steel pipe, the impact of moving from 200 mm to 300 mm pipe was larger than PVC and HDPE (**Figure 7**). There was no trend in the error shift as flow rate increased, nor was there a consistent pattern in the nature of the error shift, for example, Meters A and E shifted negatively, while B, C and D shifted positively (**Figure 5**).
- The error shift when moving from 200 mm to 300 mm HDPE pipe was greater than PVC but less than steel (**Figure 7**). Mean error appeared to decline as flow rate increased (**Figure 7**), but only slightly and there was no clear pattern in the individual HDPE meter results (Figure 6). There was no consistent pattern evident in the error shift as flow rate increased. Also like the results for PVC and steel, there was no consistent pattern in the nature of the error shift among individual meters.
- The error shift when moving from 200 mm to 600 mm HDPE was similar to the error shift moving from 200 mm to 300 mm pipe (**Figure 7**), but there was not enough data to examine if there was a trend with flow rate.
- Changes in change in relative error of measurement with pipe material could be because the effect of pipe wall roughness, pipe wall thickness and/or coating material (for steel pipes). It has been previously reported that pipe wall roughness can cause an error of up to 4% (Sanderson and Yeung, 2002). In general, pipes with a high relative roughness will produce high scattering of sound ultrasonic signal. Further, air gaps that may be occurred between the coating material and pipe material could prevent successful transmission of the ultrasound (Sanderson and Yeung, 2002; Flexim, 2016).

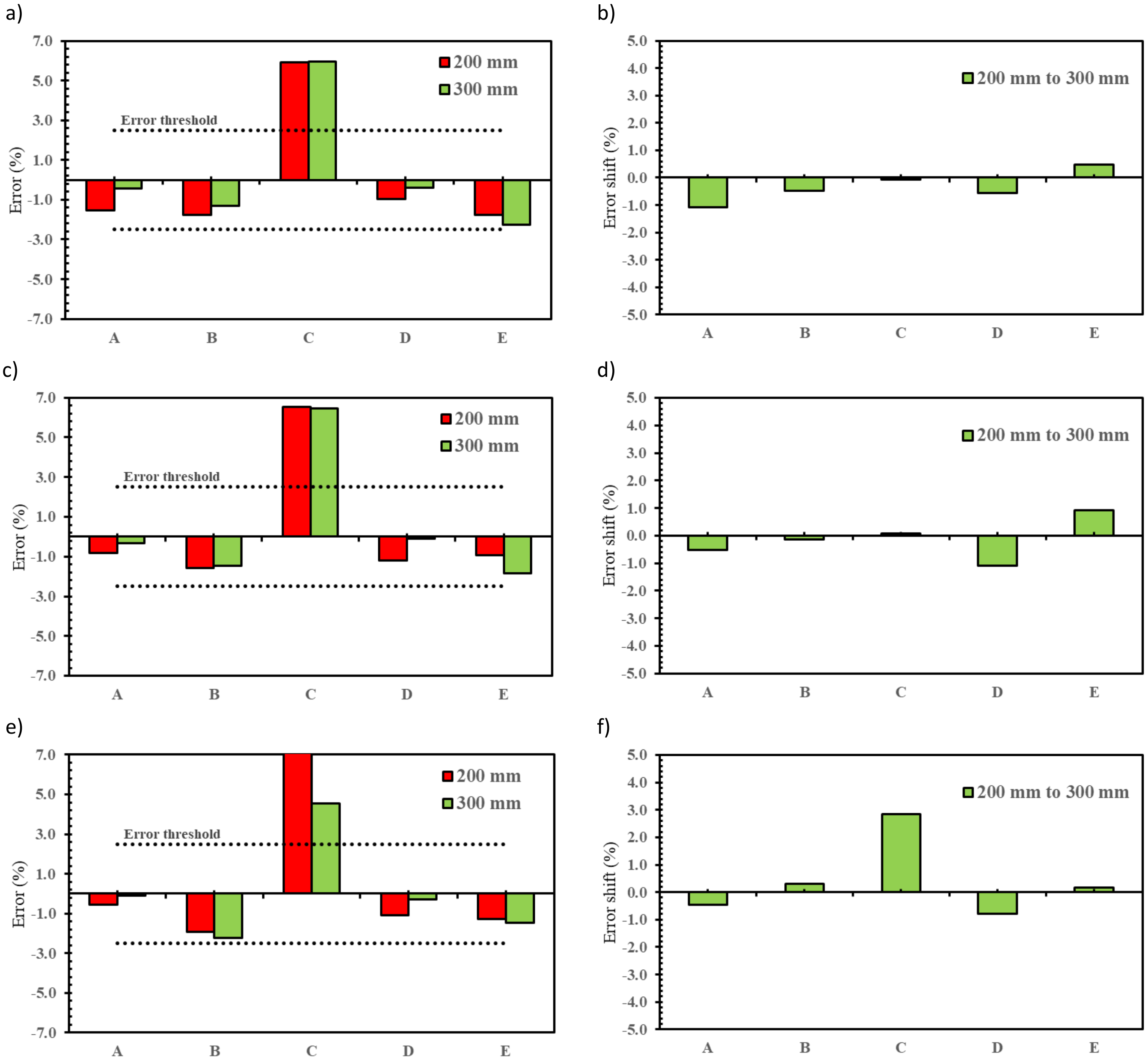

__Figure 4__ – Error of measurement test results when testing all meters on 200 mm and 300 mm PVC pipe with no disturbance upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) from 200 mm to 300 mm pipe.

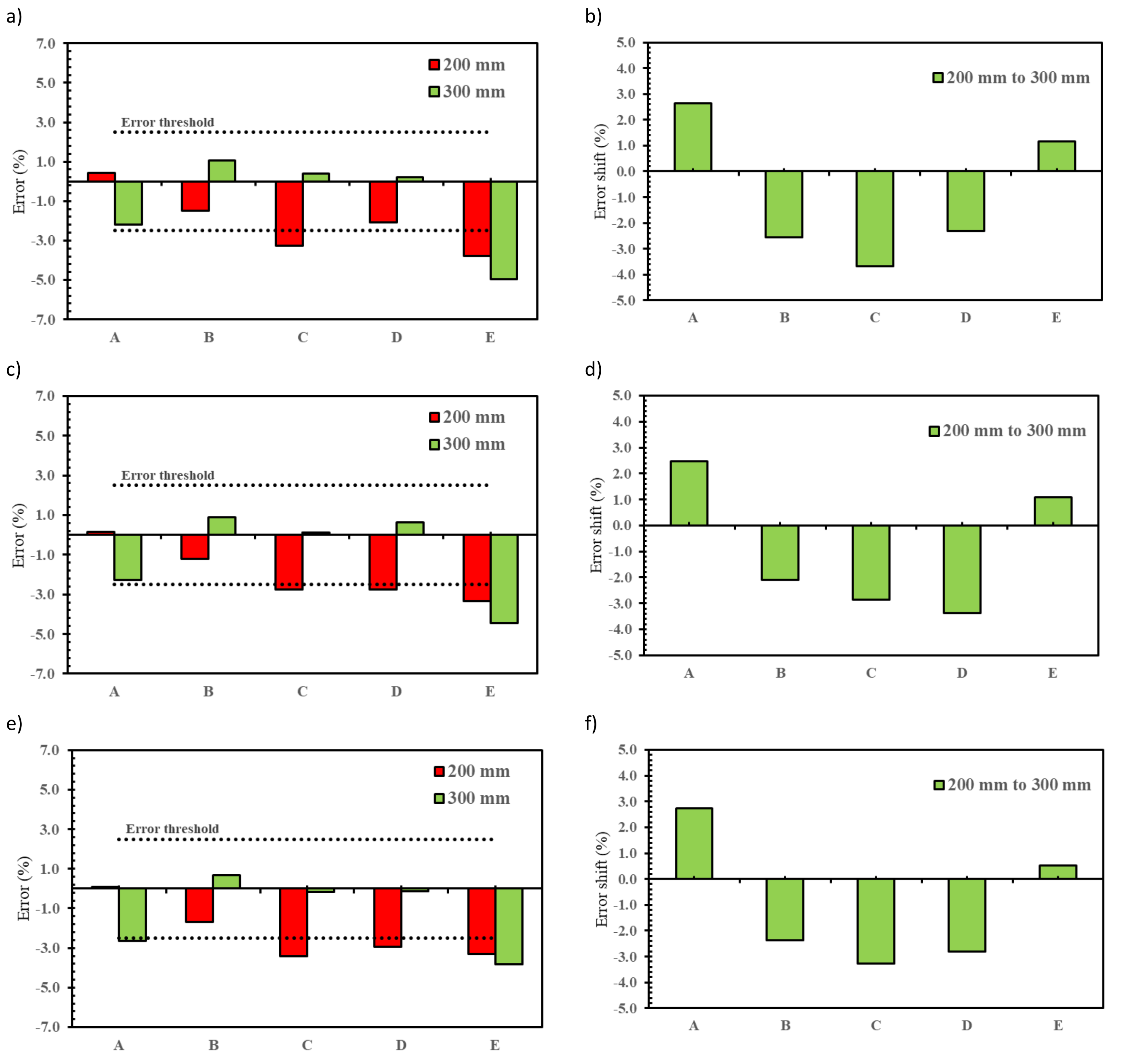

Figure 5 *- Error of measurement test results when testing all meters on 200 mm and 300 mm steel pipe with no disturbance upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) from 200 mm to 300 mm pipe.*

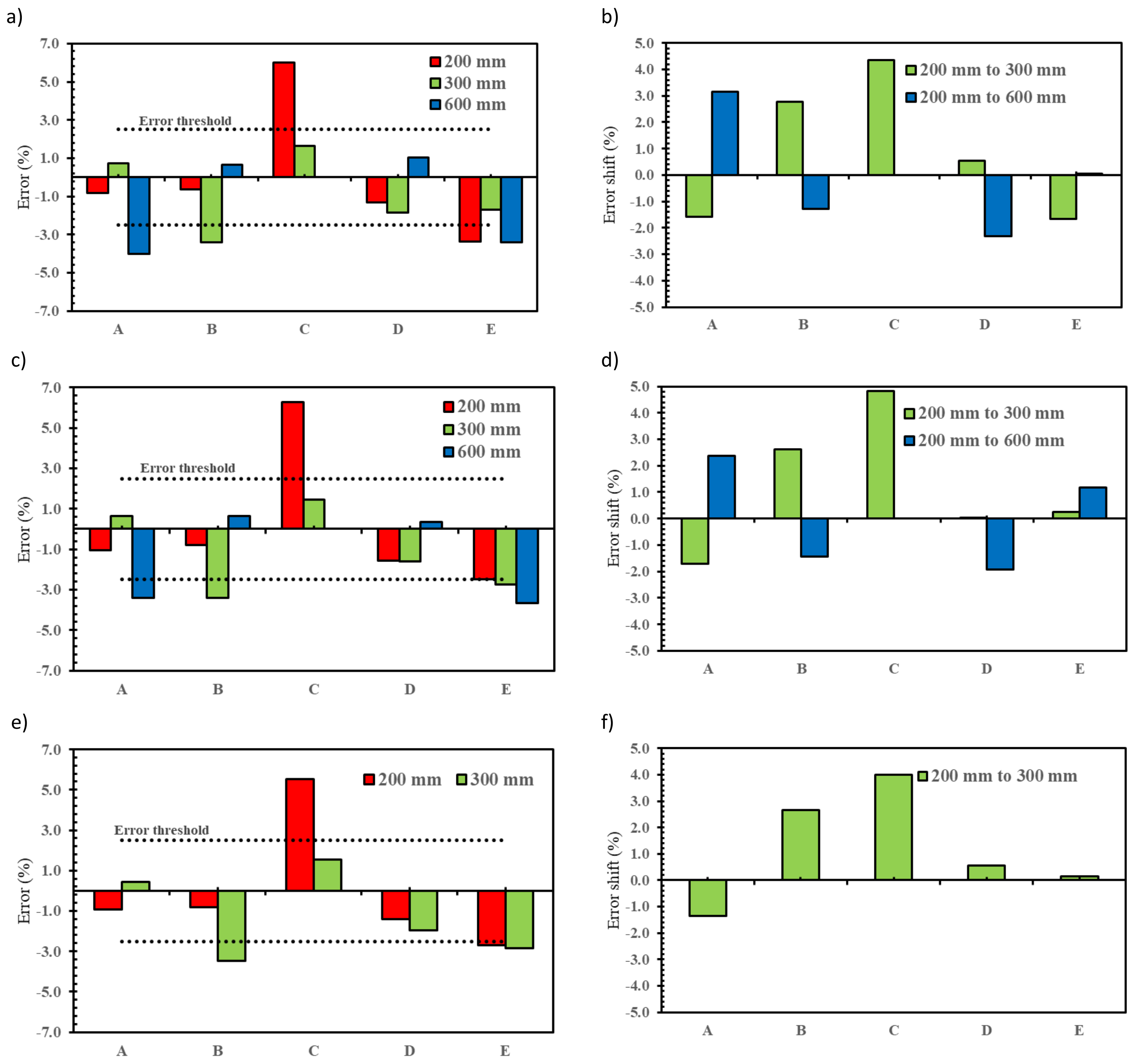

Figure 6 *- Error of measurement test results when testing all meters on 200 mm, 300 mm and 600 mm HDPE pipe with no disturbance upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) from 200 mm to 300 mm pipe, and from 200 mm to 600 mm pipe. Note there was no testing in 600 mm pipe at 3.0 m/s due to flow capacity constraints.*

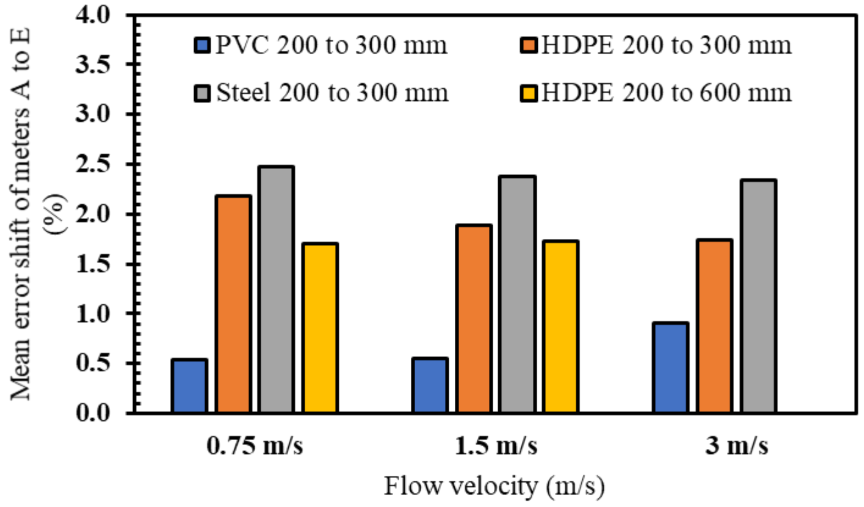

Figure 7 *- Plot of mean absolute error shift for all meters A to E when moved from 200 mm to 300 mm and from 200 to 600 mm pipe*

Table 4 *– Summary of the range of relative error of measurement determined for all meters when tested with a quarter plate disturbance situated 2, 5 and 20 pipe diameters upstream*

Pipe (mm)	**Range in absolute value of relative error of measurement across all flow rates, %**		
	PVC	**Steel**	**HDPE**
0.63 – 6.28	0.55-7.39	0.1 - 3.78	0.63 – 6.28
300	0.1 – 6.44	0.12 – 4.95	0.42 – 3.47
600	No data	No data	0.17 – 4.18

Categories:

Small	Medium	Large	Very large
< 2.5%	2.5% - 5%	5% - 8%	8% - 20%

Table 5 *– Summary of the range of error shift determined for all meters when tested on 200 mm and 300 mm pipe, or 300 mm and 600 mm pipe*

Pipe (mm)	**Range in absolute value of error shift across all flow rates, %**		
	PVC	**Steel**	**HDPE**
200 to 300	0.07 to 2.85	0.51 to 3.67	0.04 to 4.83
200 to 600	No data	No data	0.05 to 3.16
300 to 600	No data	No data	0.92 to 4.73

Categories:

Small	Medium	Large	Very large
< 2.5%	2.5% - 5%	5% - 8%	8% - 20%

***Table 6** – Summary of the range of error shift determined for all meters when moved from PVC to steel, to HDPE*

Pipe (mm)	Range in absolute value of error shift across all flow rates, %		
	PVC to steel	**HDPE to steel**	**PVC to HDPE**
200	0.24 to 10.81	0.39 to 9.26	0.1 to 1.86
300	0.18 to 6.1	0.96 to 4.48	0.52 to 4.99

Categories:

Small	Medium	Large	Very large
< 2.5%	2.5% - 5%	5% - 8%	8% - 20%

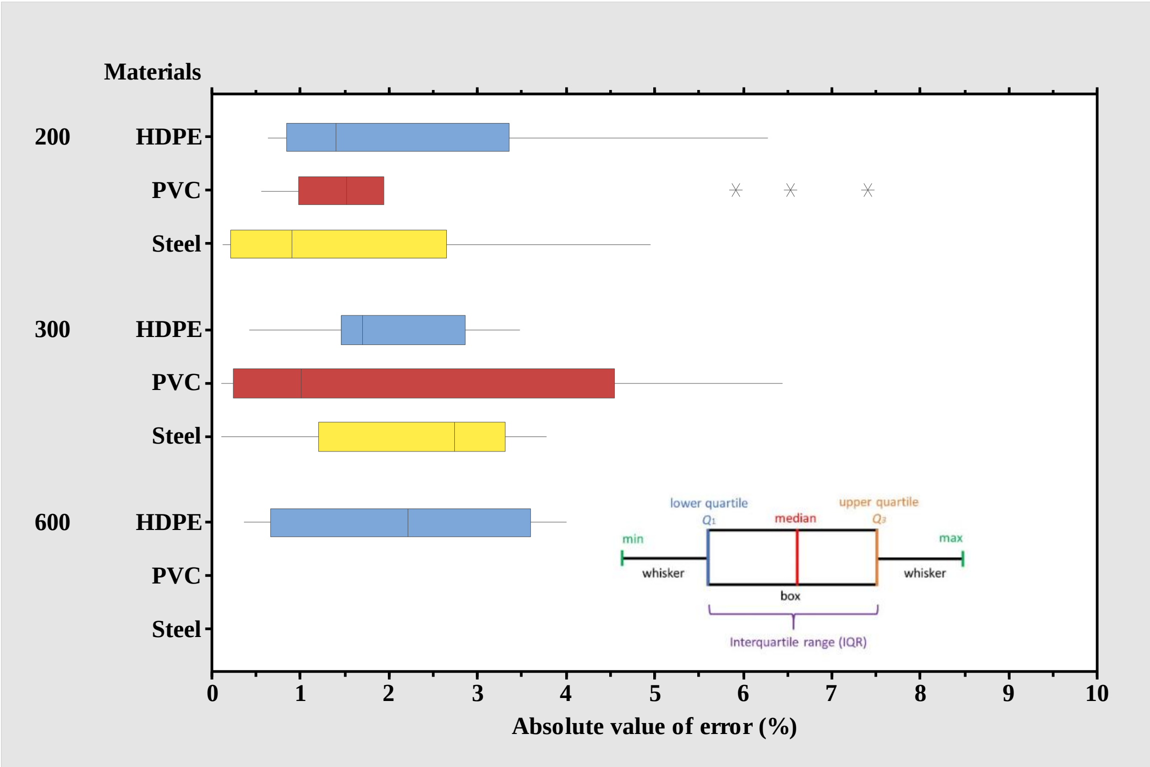

***Figure 8** - Median, 25th percentile and 75th percentile values of absolute relative error of measurement across all flow rates, for all pipe sizes and materials tested.*

3.2. Evaluate the effect of quarter plate disturbance and meter location relative to source of disturbance (e.g., elbow, pump)

The impact of disturbances on the performance of meters was assessed by examining the error shift of meters with and without disturbance applied at several distances upstream of the meter installation. The impacts of disturbances applied at an upstream length of 2D, 5D and 20D between the disturbance and the meters are shown in Section 3.3.1, 3.3.2 and 3.3.3 respectively.

3.2.1. Quarter plate disturbance at an upstream length of 2D between the disturbance and the meters

The performance of meters with PVC, steel and HDPE pipe are presented in **Figure 9**, **Figure 10** and **Figure 11** respectively. The error shift determined when changing test conditions from a setup with no disturbance to one with a quarter plate disturbance on the accuracy of all meters were also shown in **Figure 9**, **Figure 10** and **Figure 11** for PVC, steel and HDPE pipe respectively. **Table 7** summarises the ranges of relative error of measurement while **Table 8** shows the ranges of error shift values determined for all meters when tested with a quarter plate disturbance situated 2, 5 and 20 pipe diameters upstream. A boxplot illustrating the range of error of measurement data for each pipe material is presented in **Figure 18Figure 8**.

The results with a quarter plate situated 2D upstream indicate that:

- For all pipe materials, the error of measurement for all meters exceeded the adopted threshold at all flow rates.
- For all pipe sizes, the error of measurement for all meters exceeded the adopted threshold at all flow rates.
- The highest relative error of measurement was for PVC (up to 20%) followed by steel (up to 13%) then HDPE (up to 10%) as shown in **Table 7**.
- In general, for PVC pipes, the error shift when changing test conditions from a setup with no disturbance to one with a quarter plate disturbance decreased as the pipe size increased (i.e. $\%error\ shift_{PVC\_200} > \%error\ shift_{PVC\_300}$).
- In contrast, for steel and HDPE pipes, the error shift increases with the pipe size increase (i.e. $\%error\ shift_{PVC\_200} < \%error\ shift_{PVC\_300} < \%error\ shift_{PVC\_600}$)
- For all pipe sizes, the highest error shift was for PVC (up to 18%) followed by HDPE (up to 14%) then steel (up to 12%) as shown in **Table 8**.
- The impacts were considered to be of very large concern as the error shift was higher than 8% and up to 20% in most of the cases

3.2.2. Quarter plate disturbance at an upstream length of 5D between the disturbance and the meters

The performance of meters with PVC, steel and HDPE pipe are presented in **Figure 12**, **Figure 13** and **Figure 14** respectively. The error shift determined when changing test conditions from a setup with no disturbance to one with a quarter plate disturbance on the accuracy of all meters were also shown in **Figure 12**, **Figure 13** and **Figure 14** for PVC, steel and HDPE pipe respectively. A boxplot illustrating the range of error of measurement data for each pipe material is presented in **Figure 18**.

The results with a quarter plate situated 5D upstream indicate that:

- For all pipe materials, the error of measurement for all meters exceeded the adopted threshold at all flow rates.
- For all pipe sizes, the error of measurement for all meters exceeded the adopted threshold at all flow rates.
- In general, the error of measurement for all meters tested with a quarter plate disturbance situated 5D upstream of the meter was lower than corresponding values for meters tested with a quarter plate disturbance situated 2D upstream of the meter (i.e. $\%error_{1/4plate\_2D} > \%error_{1/4plate\_5D}$)
- The highest error of measurement value was for PVC (up to 11%) followed by HDPE (up to 10%) then steel (up to 5.2%) as shown in **Table 7**.
- In general, due to the small error shift results (< 5% for all cases except meter A when tested on 600 mm HDPE pipe), there was no discernible relationship between the error shift and flow rate and also between the error shift and pipe size.

- For all pipe sizes, no such differences were found for error shift values of all meters tested on PVC, steel and HDPE pipes (PVC: up to 4.5%; Steel: up to 5.1%; HDPE: up to 4.3% for all cases except meter A when tested on 600 mm HDPE pipe) as shown in **Table 8**.
- The impacts were considered to be of medium concern as the error shift was less than 5% in all cases.

3.2.3. Quarter plate disturbance at an upstream length of 20D between the disturbance and the meters

The performance of meters with PVC, steel and HDPE pipe are presented in **Figure 15**, **Figure 16** and **Figure 17** respectively. The error shift determined when changing test conditions from a setup with no disturbance to one with a quarter plate disturbance on the accuracy of all meters were also shown in **Figure 15**, **Figure 16** and **Figure 17** for PVC, steel and HDPE pipe respectively.

The results with a quarter plate situated 20D upstream indicate that:

- For all pipe materials, the error of measurement for all meters exceeded the adopted threshold at all flow rates.
- For all pipe sizes, the error of measurement for all meters exceeded the adopted threshold at all flow rates.
- In general, the error of measurement was lower for all meters as the distance between the disturbance and the meter installation increased (i.e., $\%error_{1/4plate\_2D} > \%error_{1/4plate\_5D} >= \%error_{1/4plate\_20D}$).
- The highest error of measurement was for Steel (up to 7%) followed by HDPE (up to 5.7%) then PVC (up to 5%) as shown in **Table 7**.
- Meters tested with a quarter plate disturbance situated 20D upstream of the meter were found to have the lowest error shift values (0.1 – 3.5%) followed by that for meter tested with a quarter plate disturbance situated 5D upstream of the meter (0.1 - 5.1%) then 2D upstream of the meter (0.1 – 18.2%) as shown in **Table 8** (i.e. $\%errorShift_{1/4plate\_2D} > \%\ errorShift_{1/4plate\_5D} > \%\ errorShift_{1/4plate\_20D}$).
- The impacts were considered to be of medium concern as the error shift was less than 3.5% in all cases.
- In general, due to the small error shift results (< 3.5%), there was no discernible relationship between the error shift and flow rate, nor between the error shift and pipe size as shown in **Table 8**.

These results suggest that the quarter plate disturbance had an impact on meter accuracy but the impact decreases as the upstream length between the disturbance and the meters increases. As shown in **Figure 18**, median relative error of measurement values are 1.9%, 8%, 2.4% and 3.3% for meters tested without disturbance and with quarter plate disturbances applied at an upstream length of 2D, 5D and 20D between the disturbance and the meters respectively. While 75% of the error of measurement values are equal to or less than 3.4%, 12%, 4.4% and 4.9% for meters tested without disturbance, and with ¼ plate disturbances applied at an upstream length of 2D, 5D and 20D between the disturbance and the meters respectively.

Furthermore, for all meters across all tested flow rates, maximum relative error of measurement values are 7.4%, 20%, 11% and 7% for meters tested without disturbance, and with ¼ plate disturbances applied at an upstream length of 2D, 5D and 20D between the disturbance and the meters respectively.

***Table 7** – Summary of the range of relative error of measurement determined for all meters when tested with a quarter plate disturbance situated 2, 5 and 20 pipe diameters upstream.*

Upstream length (nD)	Pipe (mm)	Range in absolute value of relative error of measurement across all flow rates, %		
		PVC	Steel	HDPE
2D	200	1.25 - 20	3.87 - 7.87	0.52 - 8.69
	300	1.19 - 12.37	4.76 - 13.21	0.25 - 9.13
	600	N/A	N/A	5.17 - 9.98
5D	200	0.09 - 11.09	0.07 - 3.61	0.09 - 10.21
	300	0.85 - 9.41	0.08 - 5.14	0.04 - 5.97
	600	N/A	N/A	0.06 - 6.73
20D	200	2.56 - 4.94	2.8 - 5.77	2.76 - 5.55
	300	1.91 - 4.49	1.12 - 7	0.2 - 5.69
	600	N/A	N/A	0.07 - 4.18

Categories:

Small	Medium	Large	Very large
< 2.5%	2.5% - 5%	5% - 8%	8% - 20%

***Table 8** – Summary of the range of error shift determined for all meters when tested with and without a quarter plate disturbance situated 2, 5 and 20 pipe diameters upstream.*

Upstream length (nD)	Pipe (mm)	Range in absolute value of error shift across all flow rates, %		
		PVC	Steel	HDPE
2D	200	7.15 - 18.24	1.57 - 4.93	0.04 - 7.4
	300	0.98 - 11.3	0.94 - 12.08	0.11 - 5.66
	600	N/A	N/A	1.87 - 13.66
5D	200	1.19 - 4.51	0.17 - 4.8	1.39 - 4.28
	300	2.47 - 4.32	1.58 - 5.01	1.48 - 4.32
	600	N/A	N/A	0.02 - 9.46*
20D	200	1.8 - 2.61	0.59 - 3.37	1.94 - 3.35
	300	1.48 - 3.51	0.05 - 2.53	1.69 - 2.77
	600	N/A	N/A	0.11 - 0.83

* Error shift determined for all meters (except meter A) tested at various flow rates were less than 3.5%

Categories:

Small	Medium	Large	Very large
< 2.5%	2.5% - 5%	5% - 8%	8% - 20%

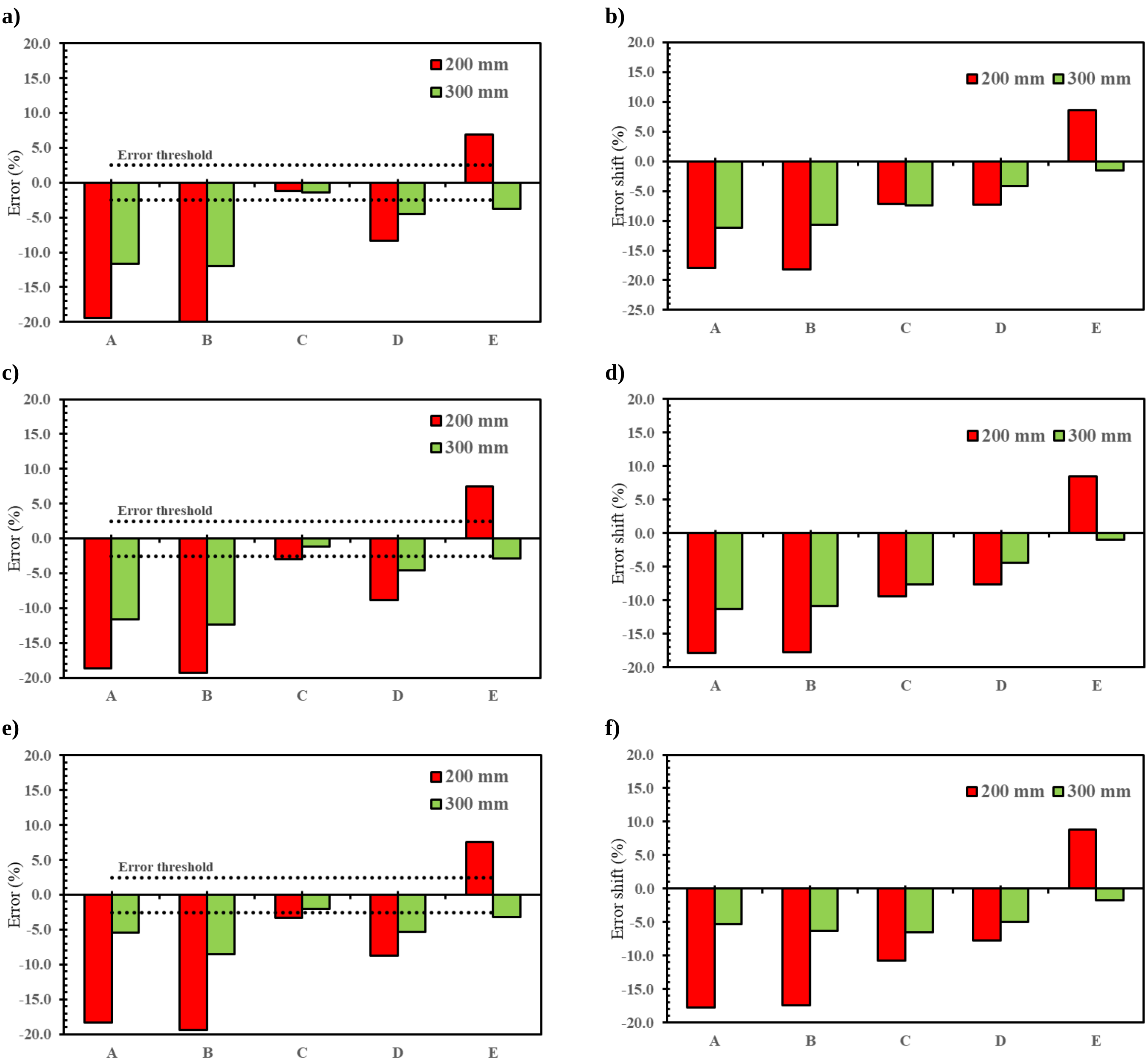

Figure 9 *- Error of measurement test results when testing all meters on 200 mm and 300 mm PVC pipe with a quarter plate disturbance situated 2D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 2D upstream of the meter installation*

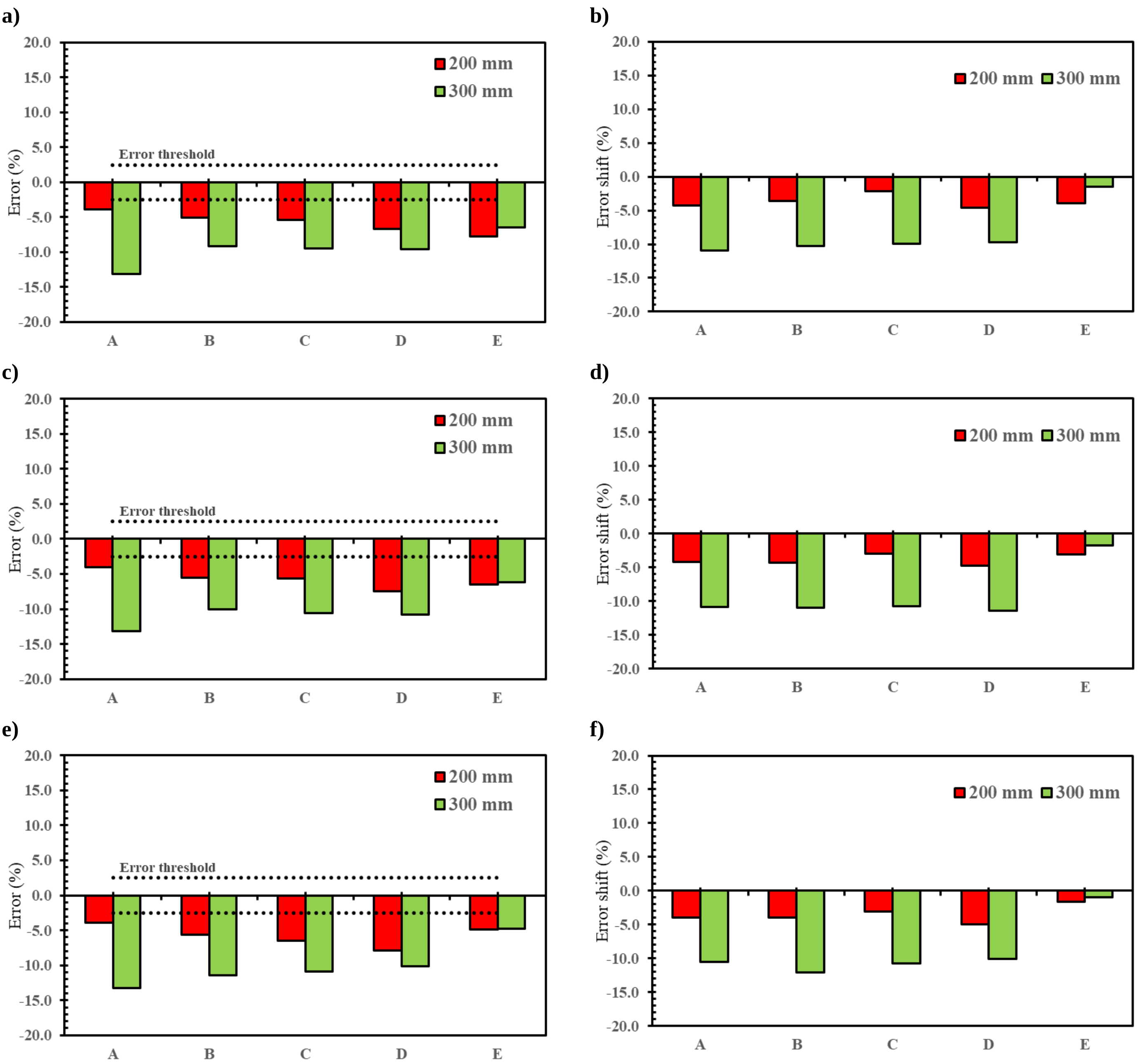

***Figure 10 -** Error of measurement test results when testing all meters on 200 mm and 300 mm Steel pipe with a quarter plate disturbance situated 2D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 2D upstream of the meter installation*

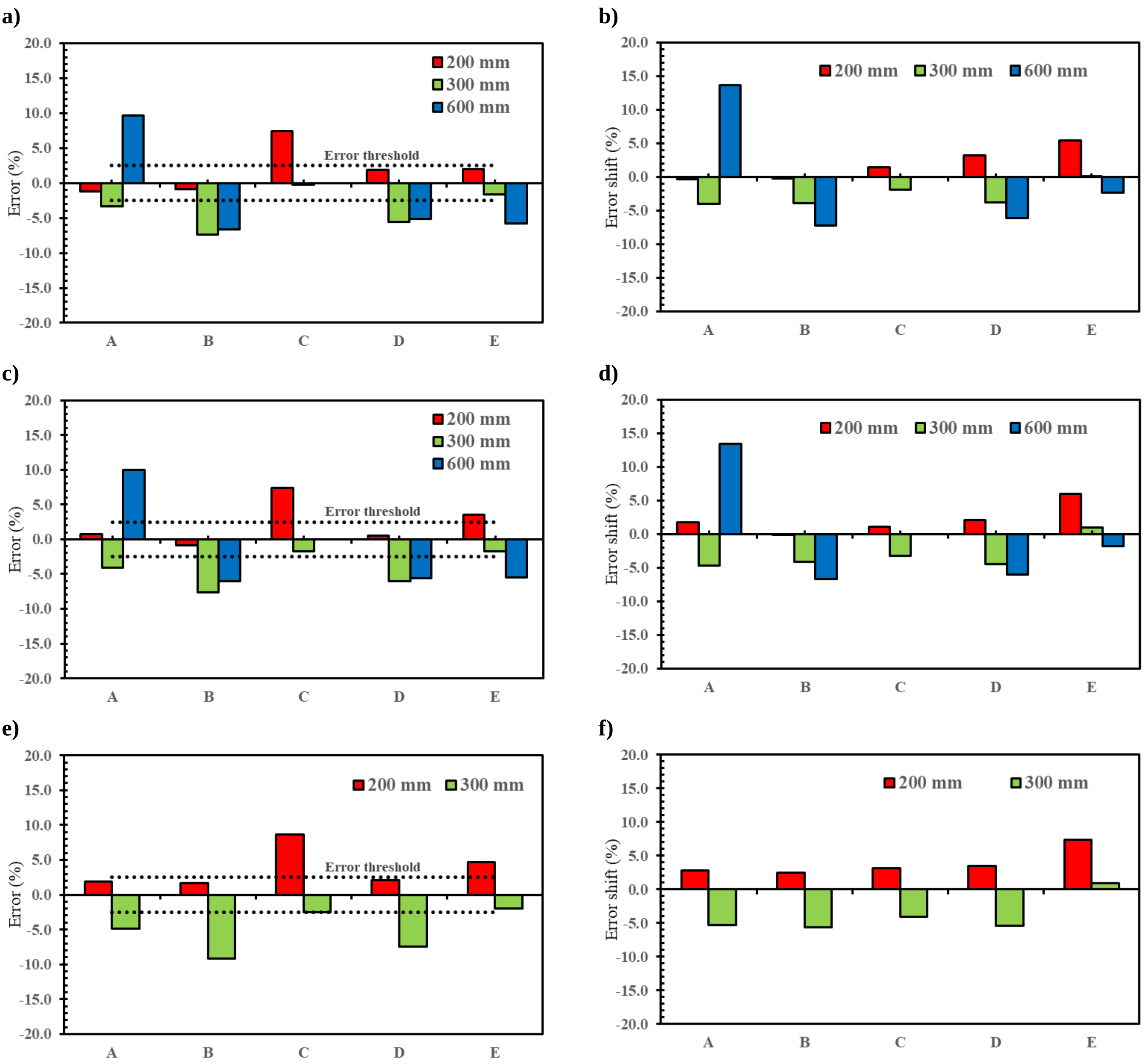

Figure 11 - *Error of measurement test results when testing all meters on 200 mm, 300 mm and 600 mm HDPE pipe with a quarter plate disturbance situated 2D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 2D upstream of the meter installation*

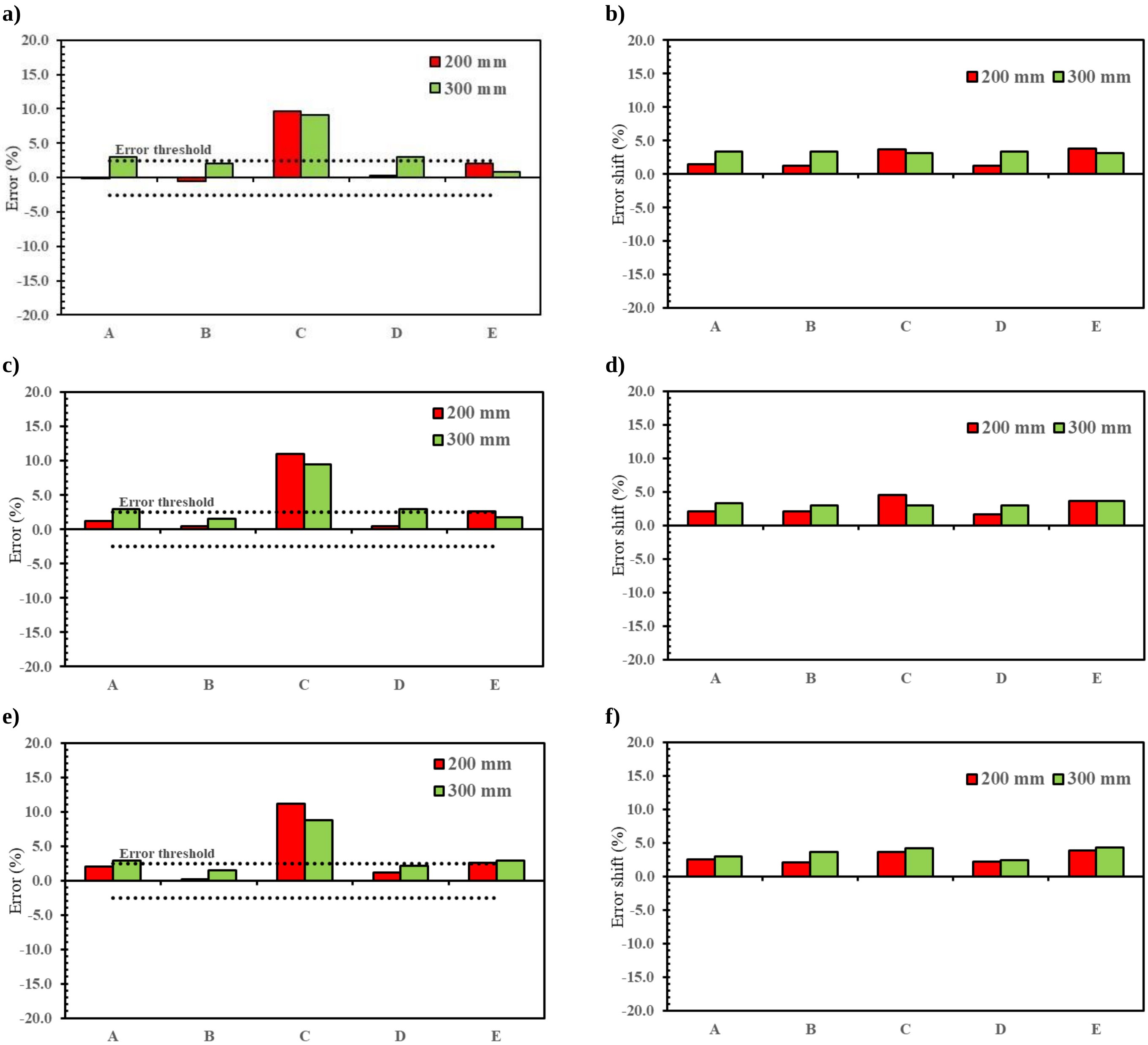

Figure 12 *- Error of measurement test results when testing all meters on 200 mm and 300 mm PVC pipe with a quarter plate disturbance situated 5D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 5D upstream of the meter installation*

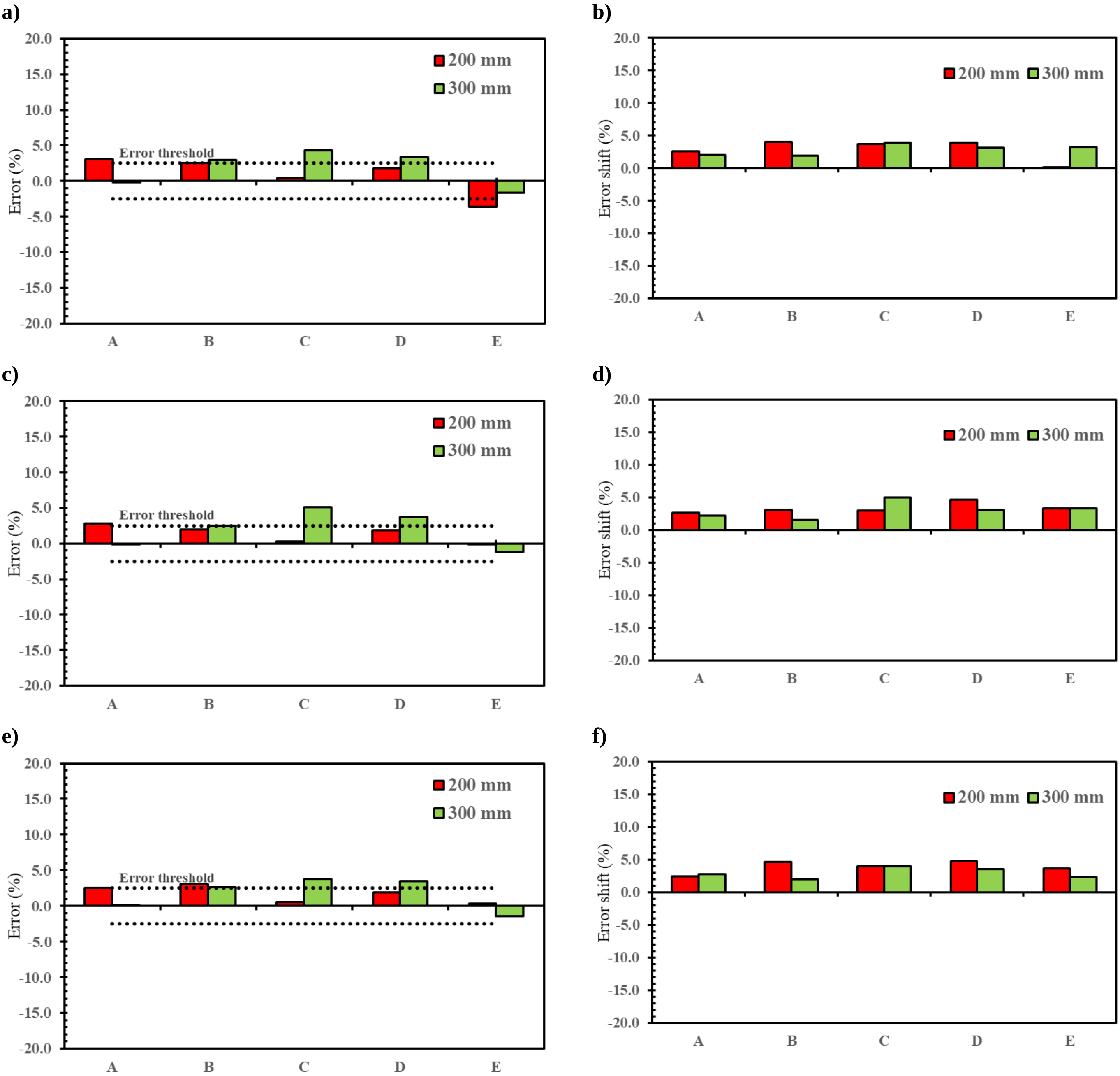

Figure 13 - *Error of measurement test results when testing all meters on 200 mm and 300 mm steel pipe with a quarter plate disturbance situated 5D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 5D upstream of the meter installation*

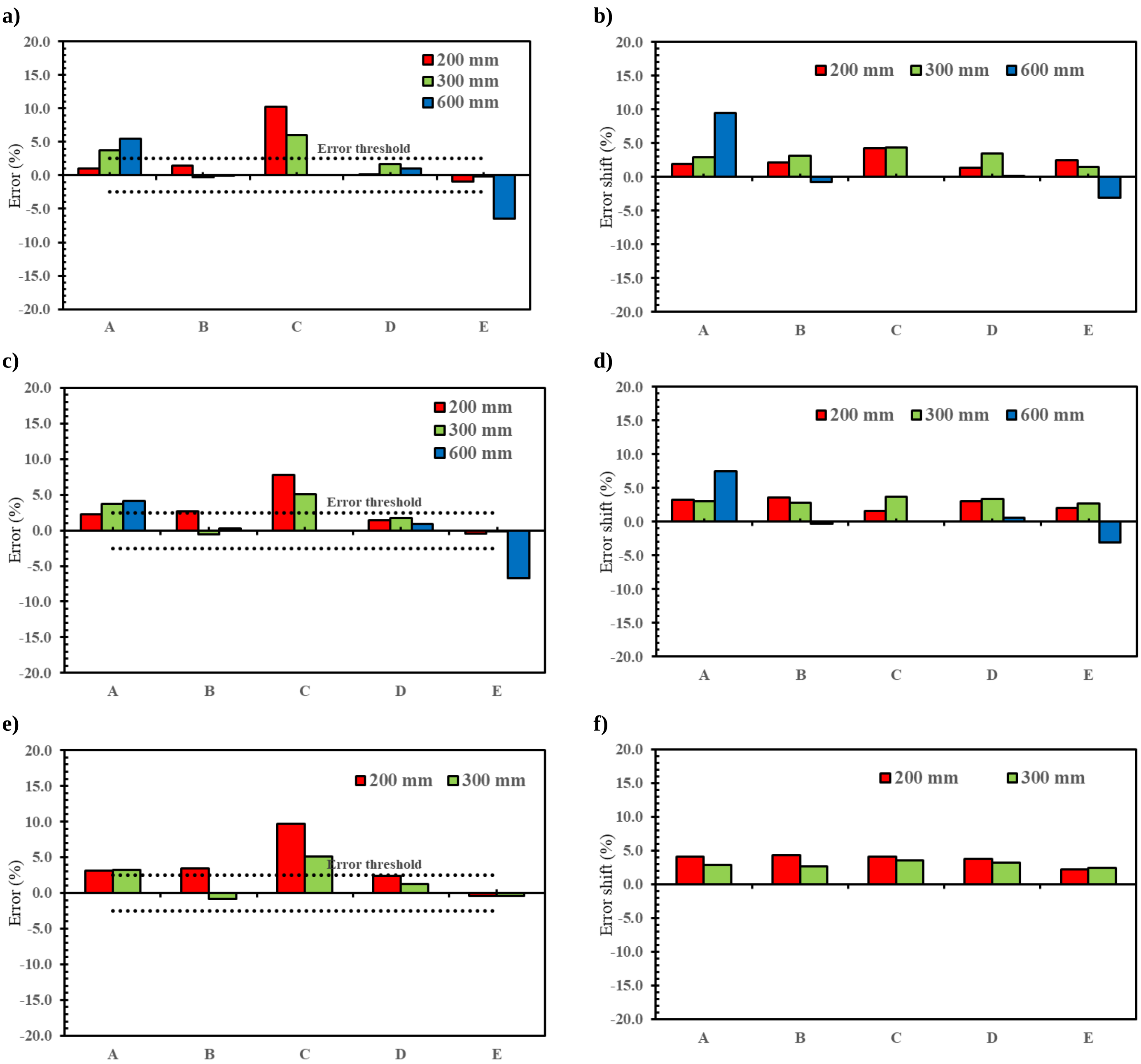

Figure 14 *- Error of measurement test results when testing all meters on 200 mm, 300 mm and 600 mm HDPE pipe with a quarter plate disturbance situated 5D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 5D upstream of the meter installation*

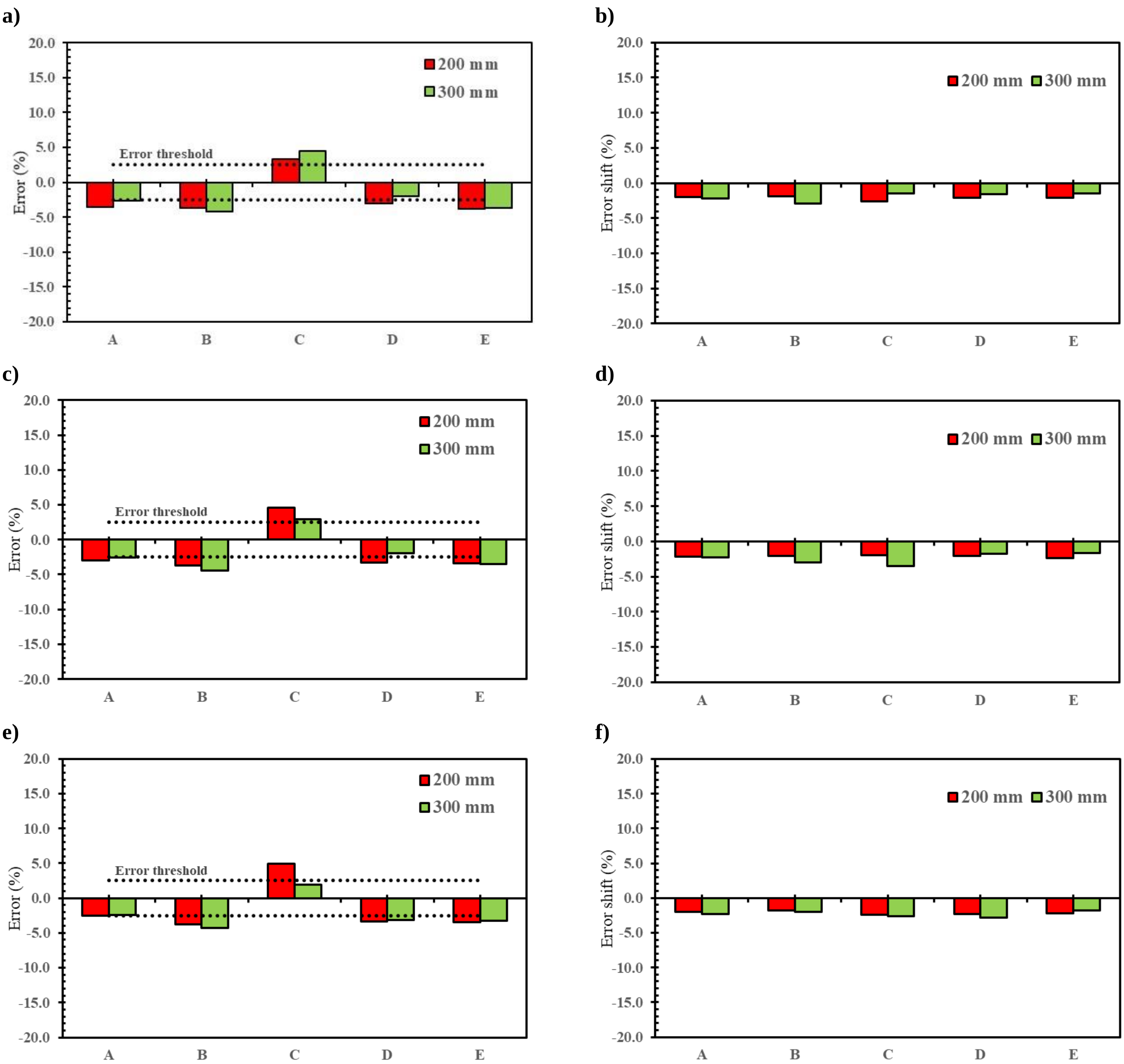

Figure 15 - *Error of measurement test results when testing all meters on 200 mm and 300 mm PVC pipe with a quarter plate disturbance situated 20D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 20D upstream of the meter installation*

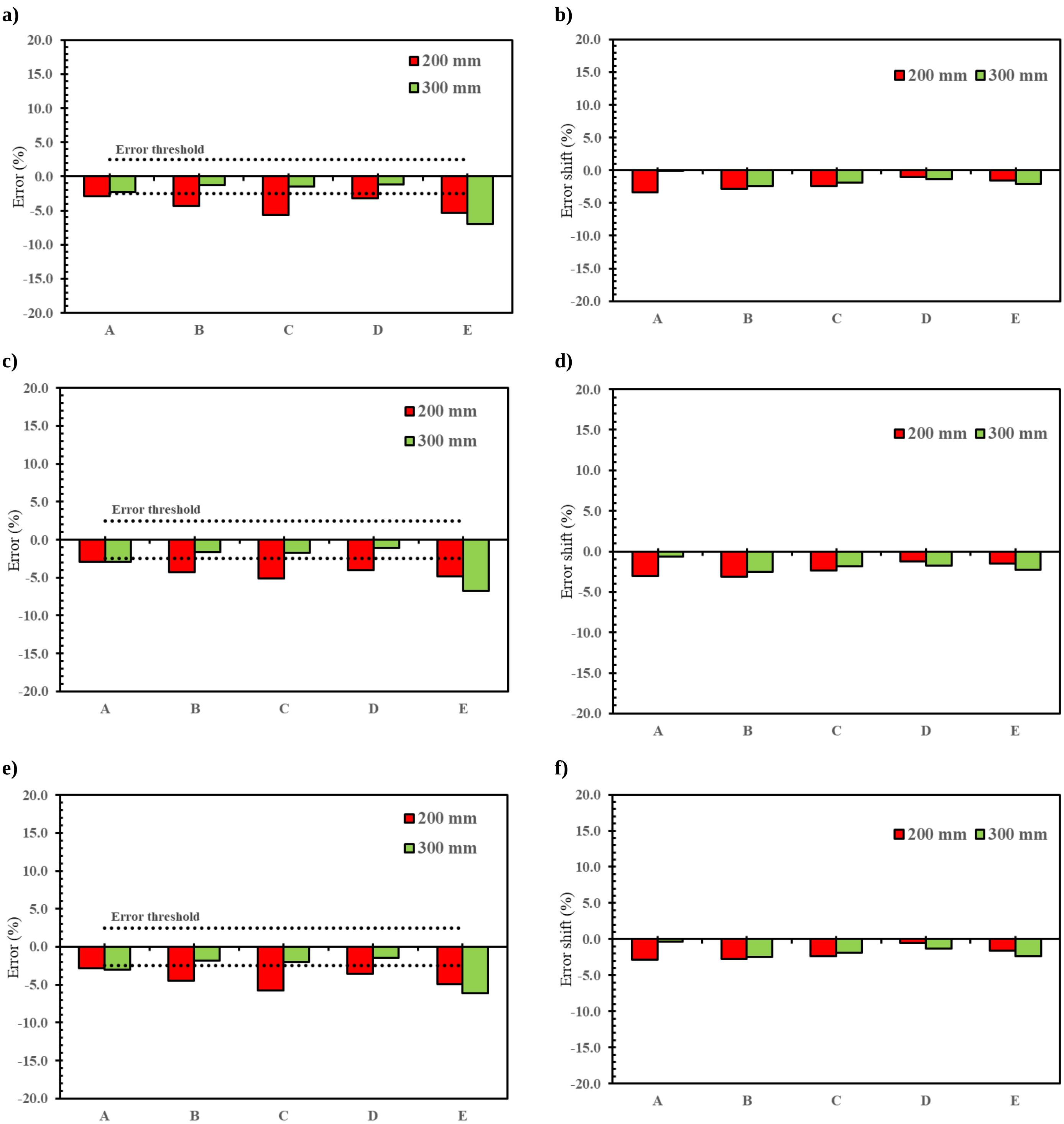

Figure 16 - Error of measurement test results when testing all meters on 200 mm and 300 mm Steel pipe with a quarter plate disturbance situated 20D upstream of the meter installation tested at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 20D upstream of the meter installation

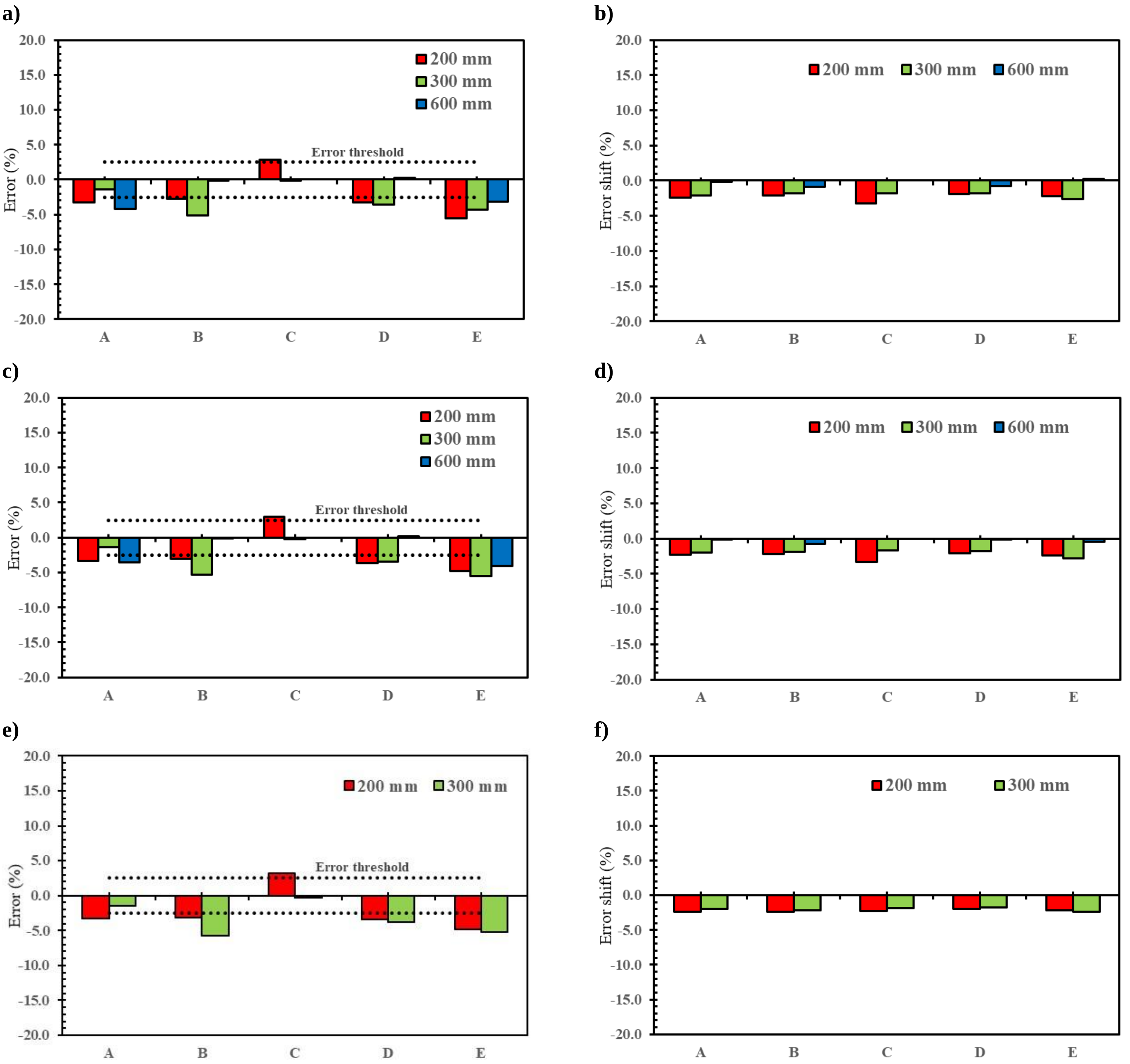

Figure 17 - *Error of measurement test results when testing all meters on 200 mm, 300 mm and 600 mm HDPE pipe with a quarter plate disturbance situated 20D upstream of the meter installation at 0.75 m/s (a), 1.5 m/s (c) and 3.0 m/s (e). The error shift when all meters were tested at 0.75 m/s (b), 1.5 m/s (d) and 3.0 m/s (f) with and without a quarter plate disturbance situated 20D upstream of the meter installation*

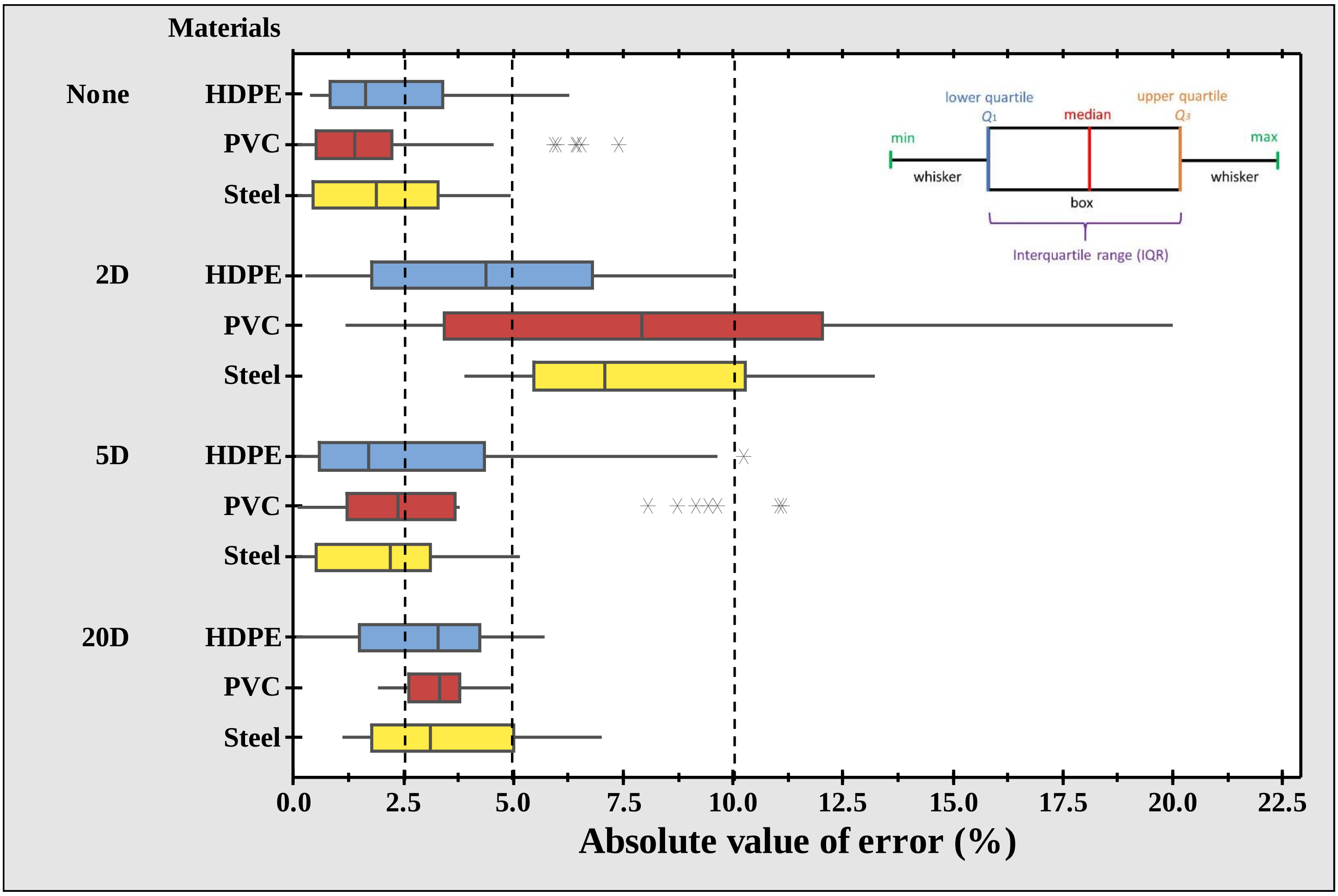

Figure 18 - Median, 25th Percentile and 75th Percentile values of absolute relative error of measurement across all flow rates when exposed to quarter plate disturbance placed 2D, 5D or 20D upstream of the test meters

3.3. Evaluate the effect of poor water quality (sediment) on meter performance

The impact of poor water quality (sediment) on the error of measurement performance of the water meters was examined by determining the error shift that occurred to a water meter with and without the presence of sediment in accordance with the procedure in **Section 2.3**. The error shift results for all water meters are presented in **Figure 19**.

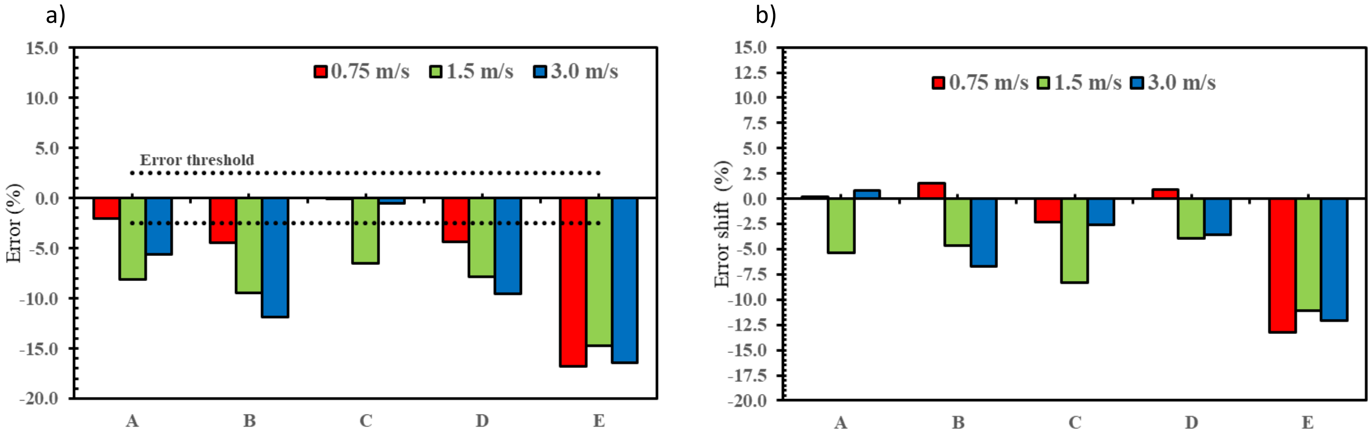

***Figure 19** – Water quality (sediment) test results showing (a) Error of measurement test results when testing all meters on 200 mm HDPE pipe with 3 g/L ± 0.3 g/L in water at a flow velocities of 0.75 m/s, 1.5 m/s, and 3.0 m/s and (b) The error shift when all meters were tested at 0.75 m/s , 1.5 m/s (d) and 3.0 m/s (f) with and without the sediment in the water*

- The results indicate there was a reasonable error shift that occurred when the ultrasonic meters were exposed to water with sediment. Error shift ranged from 0.22% to 25.5% with a 75th percentile of error shift of 8.3% (**Figure 20**), indicating that the error shift of the meters was a 'large' concern.
- There did not appear to be a trend in the error shift when exposed to sediment as flow rate increased. Meter B and E appeared to have an increasing error as flow rate increased when exposed to sediment, but this was not apparent for other meters, nor when values were averaged.

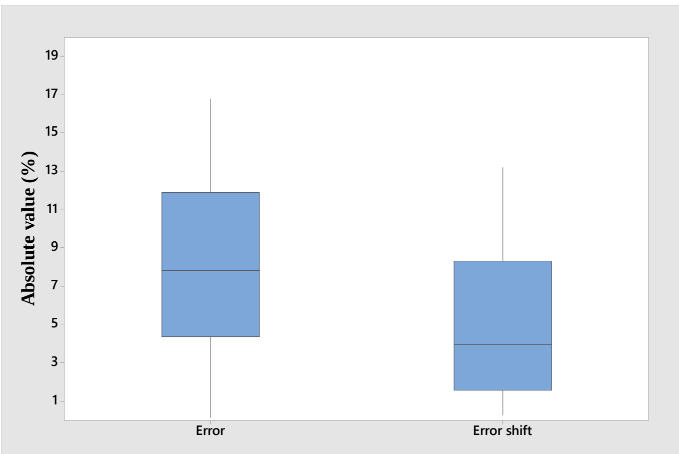

***Figure 20** - Median, 25th Percentile and 75th Percentile values of absolute relative error of measurement and error shift across all flow rates when exposed to water with sediment*

3.4. Evaluate the effect of air in the flow on the meter's performance

To examine the impact of proximity of the flow disturbance to the clamp on ultrasonic water meter performance, the error of measurement (and resulting error shift from the baseline no disturbance case) was determined when the test meters were exposed to the presence of air at five air flow rates (1, 2.5, 5, 10 and 20 m^3/h) corresponding to five different air to water volume ratios (0.6, 1.5, 2.9, 5.9 and 11.8%). The performance of meters with the presence of air are presented in **Figure 21**. **Figure 21** also shows the error shift determined when changing test conditions from a setup with no disturbance to one with the presence of air.

The results from comparing the effects of the presence of air indicate that:

- The presence of air at 1, 2.5 and 5 m^3/h air flow rates (equivalent to air/water ratio of 0.6, 1.5 and 2.9%) had an impact on the error of measurement performance of the EUTs. The impacts were considered to be of medium concern as the error shift when moving from standard condition (no air) to one with the presence of air was less than 5% in all cases (**Figure 21**b).
- The presence of air at higher flow rates (i.e., 10 and 20 m^3/h) had a significant impact on the EUTs' performance. The impacts were considered to be of 'very large' concern.
- For three meters (A, D and E), the error shift was more than 50% when the meters tested with the presence of air at 10 m^3/h. In contrast, for the remaining meters (B and C), the error shift values were less than 6% when tested under the same condition, as shown in **Figure 21**d.
- Four meters (A, B, D and E) did not able to record any measurements when these tested with the presence of air at 20 m^3/h. However, the error shift for Meter C was 6.3% as shown in **Figure 21**d.

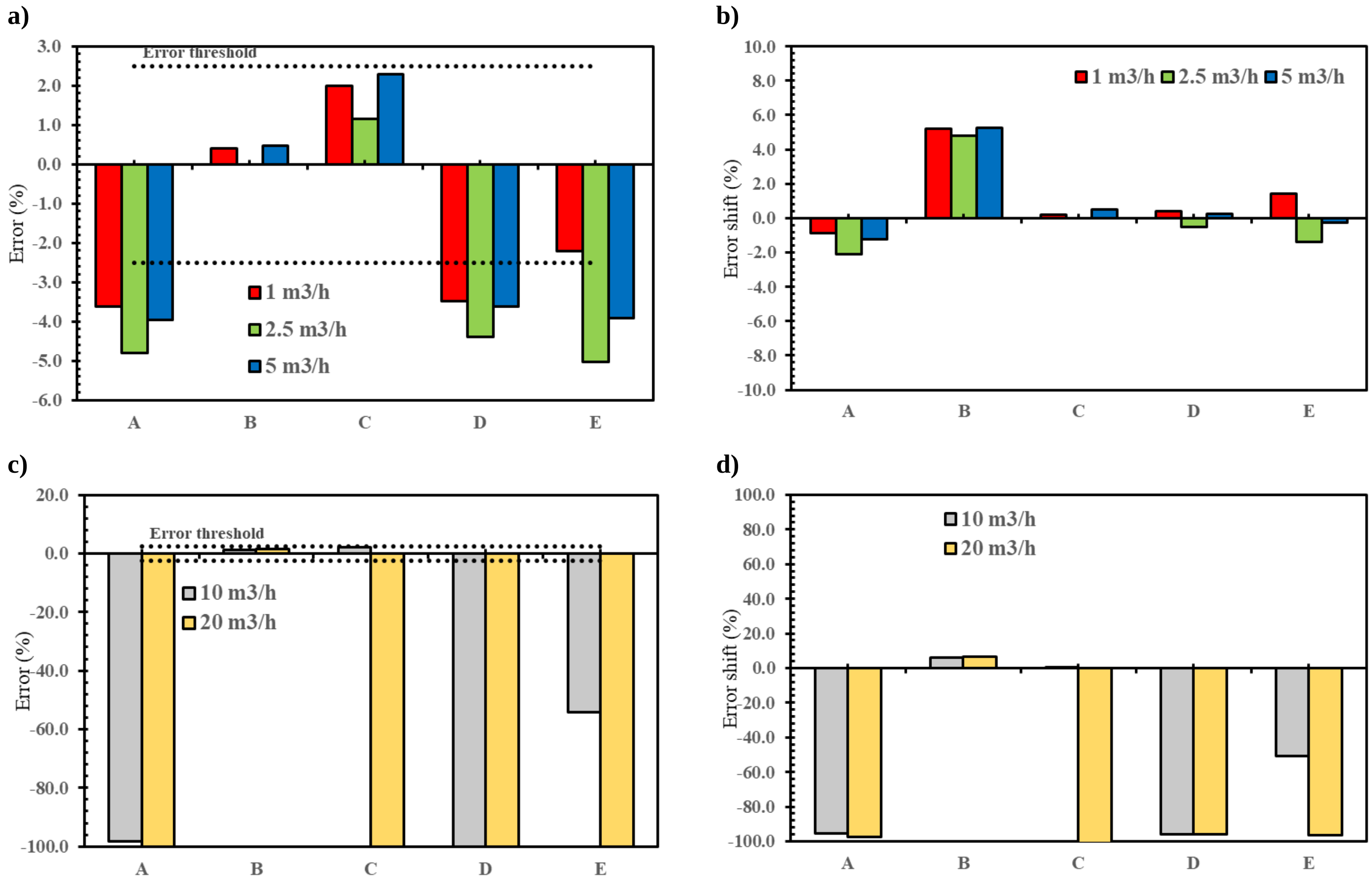

__Figure 21__ - Error of measurement test results when testing all meters on 200 HDPE pipe with the presence of air at 1.0, 2.0 and 5.0 m^3/h (a), and 10 and 20 m^3/h (c). The error shift when all meters were tested air flow rates of 1.0, 2.0 and 5.0 m^3/h, and 10 and 20 m^3/h (d).

4. Conclusion and recommendation

The results indicate that the error of measurement for the ultrasonic clamp on meters was influenced when the meters were moved from smaller to larger pipes, and when moving to different pipe materials, as evidenced by error shift results. When meters were moved from smaller to larger pipe sizes, the impacts were of medium concern (less than 5%). However, for a given pipe size, changing the pipe materials had a larger impact than changing pipe size.

The results for switching the meter from HDPE and PVC pipe were generally consistent showing a small to medium impact on error of measurement. However, when moving from HDPE or PVC to steel, the error shift was up to 10.8% in some cases but the 75% of the error of measurement values were less than 5% (medium concern).

The results also indicate that the error of measurement for the ultrasonic clamp on meters was influenced when the meters were exposed to the quarter plate disturbance (used in test standards to simulate typical flow disturbance conditions caused by valves) but the impact decreased as the upstream length between the disturbance and the meters increased, as evidenced by error shift results. When the quarter plate disturbances were applied at an upstream length of 2D between the disturbance and the meters, the impacts were considered to be of 'very large' concern as the error shift was higher than 8% and up to 20% in most of the cases. However, the impacts were considered to be of medium concern when the quarter plate disturbances were applied at an upstream length of 5D and 20D as the error shift was less than 5% and 3.5% in all cases, respectively.

The impacts of the presence of air at 1, 2.5 and 5 m^3/h flow rates were considered to be of medium concern as the error shift when moving from standard condition (no air) to one with the presence of air was less than 5% in all cases. In contrast, the presence of air at higher flow rate (10 m^3/h equivalent to air/water volume ratio of ~6%) had a significant impact on the EUTs' performance and the impact was considered to be of 'very large' concern (values were 50% or higher in most cases). The presence of air inside the pipeline at an air/water volume ratio of ~12% (meters tested at air and water flow rates of 20 m^3/h and 170 m^3/h respectively) produced error messages on all meters.

There are several recommendations that can be made based on this research.

- Air was found to have the highest impact on meter performance in this study. As such, it is recommended that air is bled out of all pipe work (e.g., by using air bleed valves until no more air is leaving the valves whilst water is flowing) when using clamp on ultrasonic water meters for in-situ meter verification for non-urban water meters.
- Sediment was also shown to have high impacts on meter performance. Based on this, it is recommended that the water quality of source water be characterised prior to testing water meters. At present, there is no in-situ method to estimate the level of total suspended solids in water, however there may be potential to develop a water quality threshold based on turbidity. It is also noted that at present, the influence of water quality (sediment) on the performance of pattern approved water meters is limited to some mechanical flow meters.
- Based on the error shift results for pipe material changes, the results suggest that a correction factor applied following calibration of a meter in one material may not be consistent across all pipe materials. As such meter accuracy testing should be conducted on at least two pipe materials i.e., steel and PVC or HDPE, and perhaps other materials based on a review of typical pipe materials used in field conditions.
- Information about the typical error shift of ultrasonic clamp on meters is currently not available, and further research (or documentation of existing experience) is recommended to establish a required calibration interval for ultrasonic clamp on water meters. We note that a calibration interval of 12 months is used for all electromagnetic reference meters in the AFMG laboratory.
- In this project, the effect of pipe size, material and three types of disturbances on the clamp on ultrasonic water meters were tested. We note that other factors (e.g., those included in pattern approval testing such as the presence of swirl disturbance and exposure of the EUT to standard environmental conditions) was not considered. As such, it is recommended that clamp on ultrasonic meters selected for use as reference meters be pattern

approved before use for in-situ meter verification as these other disturbance factors are considered during the pattern approval testing program.

5. Appendix

***Table 9** – Error of measurement test results when testing all meters without disturbance*

Test No.	Pipe material	Pipe size (mm)	Disturbance	Upstream length (nD)	Upstream length (mm)	Velocity (m/s) ± 0.1	EUT A	B	C	D	E
1a	PVC	200	None	20	4000	0.75 m/s	-1.52	-1.76	5.90	-0.97	-1.75
1b	PVC	300	None	20	6000	0.75 m/s	-0.43	-1.29	5.97	-0.41	-2.24
6a	PVC	200	None	20	4000	1.5 m/s	-0.82	-1.59	6.52	-1.20	-0.95
6b	PVC	300	None	20	6000	1.5 m/s	-0.31	-1.45	6.44	-0.10	-1.86
11a	PVC	200	None	20	4000	3 m/s	-0.55	-1.93	7.39	-1.08	-1.29
11b	PVC	300	None	20	6000	3 m/s	-0.10	-2.23	4.54	-0.30	-1.47
16a	HDPE	200	None	20	4000	0.75 m/s	-0.84	-0.63	6.00	-1.30	-3.35
16b	HDPE	300	None	20	6000	0.75 m/s	0.73	-3.40	1.65	-1.85	-1.69
16c	HDPE	600	None	17.5	10500	0.75 m/s	-4.00	0.66	Not tested	1.02	-3.40
21a	HDPE	200	None	20	4000	1.5 m/s	-1.04	-0.80	6.28	-1.56	-2.49
21b	HDPE	300	None	20	6000	1.5 m/s	0.66	-3.41	1.45	-1.60	-2.74
21c	HDPE	600	None	17.5	10500	1.5 m/s	-3.41	0.65	Not tested	0.36	-3.66
26a	HDPE	200	None	20	4000	3 m/s	-0.92	-0.80	5.53	-1.39	-2.71
26b	HDPE	300	None	20	6000	3 m/s	0.42	-3.47	1.53	-1.95	-2.86
31a	Steel	200	None	20	4000	0.75 m/s	0.45	-1.48	-3.26	-2.09	-3.78
31b	Steel	300	None	20	6000	0.75 m/s	-2.20	1.08	0.41	0.21	-4.95
36a	Steel	200	None	20	4000	1.5 m/s	0.17	-1.19	-2.74	-2.74	-3.35
36b	Steel	300	None	20	6000	1.5 m/s	-2.29	0.90	0.13	0.63	-4.43
41a	Steel	200	None	20	4000	3 m/s	0.10	-1.69	-3.42	-2.94	-3.31
41b	Steel	300	None	20	6000	3 m/s	-2.64	0.68	-0.16	-0.12	-3.82

***Table 10** – Error of measurement test results when testing all meters with a quarter plate disturbance situated 2D upstream of the meter installation*

Test No.	Pipe material	Pipe size (mm)	Disturbance	Upstream length (nD)	Upstream length (mm)	Velocity (m/s) ± 0.1	EUT				
							A	B	C	D	E
2a	PVC	200	1/4 plate	2	400	0.75	-19.41	-20.00	-1.25	-8.32	6.87
2b	PVC	300	1/4 plate	2	600	0.75	-11.64	-12.02	-1.46	-4.54	-3.76
7a	PVC	200	1/4 plate	2	400	1.5	-18.69	-19.31	-2.93	-8.86	7.48
7b	PVC	300	1/4 plate	2	600	1.5	-11.61	-12.37	-1.19	-4.53	-2.84
12a	PVC	200	1/4 plate	2	400	3.0	-18.33	-19.38	-3.33	-8.78	7.55
12b	PVC	300	1/4 plate	2	600	3.0	-5.38	-8.49	-2.00	-5.30	-3.19
17a	HDPE	200	1/4 plate	2	400	0.75	-1.17	-0.88	7.45	1.91	2.04
17b	HDPE	300	1/4 plate	2	600	0.75	-3.30	-7.33	-0.25	-5.62	-1.58
17c	HDPE	600	1/4 plate	2	1200	0.75	9.66	-6.63	Not tested	-5.17	-5.81
22a	HDPE	200	1/4 plate	2	400	1.5	0.70	-0.84	7.36	0.52	3.48
22b	HDPE	300	1/4 plate	2	600	1.5	-4.07	-7.60	-1.78	-6.04	-1.75
22c	HDPE	600	1/4 plate	2	1200	1.5	9.98	-6.02	Not tested	-5.63	-5.53
27a	HDPE	200	1/4 plate	2	400	3.0	1.87	1.66	8.69	2.08	4.69
27b	HDPE	300	1/4 plate	2	600	3.0	-4.85	-9.13	-2.56	-7.41	-1.95
32a	Steel	200	1/4 plate	2	400	0.75	-3.87	-5.11	-5.37	-6.64	-7.76
32b	Steel	300	1/4 plate	2	600	0.75	-13.12	-9.18	-9.52	-9.56	-6.46
37a	Steel	200	1/4 plate	2	400	1.5	-4.04	-5.50	-5.67	-7.52	-6.46
37b	Steel	300	1/4 plate	2	600	1.5	-13.14	-10.09	-10.64	-10.85	-6.14
42a	Steel	200	1/4 plate	2	400	3.0	-3.87	-5.67	-6.47	-7.87	-4.88
42b	Steel	300	1/4 plate	2	600	3.0	-13.21	-11.40	-10.85	-10.14	-4.76

***Table 11** – Error of measurement test results when testing all meters with a quarter plate disturbance situated 5D upstream of the meter installation*

Test No.	Pipe material	Pipe size (mm)	Disturbance	Upstream length (nD)	Upstream length (mm)	Velocity (m/s) ± 0.1	EUT				
							A	B	C	D	E
3a	PVC	200	1/4 plate	5	1,000	0.75	-0.09	-0.57	9.63	0.22	2.04
3b	PVC	300	1/4 plate	5	1,500	0.75	2.94	2.04	9.14	2.97	0.85
8a	PVC	200	1/4 plate	5	1,000	1.5	1.24	0.48	11.03	0.46	2.65
8b	PVC	300	1/4 plate	5	1,500	1.5	2.98	1.52	9.41	2.91	1.78
13a	PVC	200	1/4 plate	5	1,000	3.0	2.02	0.13	11.09	1.17	2.59
13b	PVC	300	1/4 plate	5	1,500	3.0	2.84	1.46	8.70	2.17	2.85
18a	HDPE	200	1/4 plate	5	1,000	0.75	1.03	1.49	10.21	0.09	-0.92
18b	HDPE	300	1/4 plate	5	1,500	0.75	3.69	-0.27	5.97	1.63	-0.21
18c	HDPE	600	1/4 plate	5	3,000	0.75	5.46	-0.06	Not tested	1.04	-6.43
23a	HDPE	200	1/4 plate	5	1,000	1.5	2.25	2.72	7.81	1.44	-0.51
23b	HDPE	300	1/4 plate	5	1,500	1.5	3.72	-0.59	5.09	1.76	-0.04
23c	HDPE	600	1/4 plate	5	3,000	1.5	4.10	0.32	Not tested	0.94	-6.73
28a	HDPE	200	1/4 plate	5	1,000	3.0	3.12	3.48	9.65	2.35	-0.45
28b	HDPE	300	1/4 plate	5	1,500	3.0	3.26	-0.79	5.11	1.24	-0.41
33a	Steel	200	1/4 plate	5	1,000	0.75	3.04	2.54	0.45	1.78	-3.61
33b	Steel	300	1/4 plate	5	1,500	0.75	-0.19	2.94	4.35	3.36	-1.68
38a	Steel	200	1/4 plate	5	1,000	1.5	2.81	1.91	0.27	1.89	-0.07
38b	Steel	300	1/4 plate	5	1,500	1.5	-0.11	2.48	5.14	3.76	-1.15
43a	Steel	200	1/4 plate	5	1,000	3.0	2.57	3.01	0.52	1.86	0.38
43b	Steel	300	1/4 plate	5	1,500	3.0	0.08	2.68	3.83	3.45	-1.47

***Table 12** – Error of measurement test results when testing all meters with a quarter plate disturbance situated 20D upstream of the meter installation*

Test No.	Pipe material	Pipe size (mm)	Disturbance	Upstream length (nD)	Upstream length (mm)	Velocity (m/s) ± 0.1	EUT				
							A	B	C	D	E
4a	PVC	200	1/4 plate	20	4,000	0.75	-3.51	-3.65	3.29	-3.09	-3.86
4b	PVC	300	1/4 plate	20	6,000	0.75	-2.62	-4.20	4.49	-2.02	-3.72
9a	PVC	200	1/4 plate	20	4,000	1.5	-2.95	-3.68	4.60	-3.27	-3.35
9b	PVC	300	1/4 plate	20	6,000	1.5	-2.62	-4.45	2.93	-1.91	-3.53
14a	PVC	200	1/4 plate	20	4,000	3.0	-2.56	-3.73	4.94	-3.35	-3.45
14b	PVC	300	1/4 plate	20	6,000	3.0	-2.38	-4.25	1.91	-3.17	-3.23
19a	HDPE	200	1/4 plate	20	4,000	0.75	-3.27	-2.76	2.81	-3.24	-5.55
19b	HDPE	300	1/4 plate	20	6,000	0.75	-1.38	-5.16	-0.20	-3.61	-4.33
19c	HDPE	600	1/4 plate	17.5	10,500	0.75	-4.18	-0.17	Not tested	0.27	-3.14
24a	HDPE	200	1/4 plate	20	4,000	1.5	-3.35	-3.01	2.93	-3.64	-4.85
24b	HDPE	300	1/4 plate	20	6,000	1.5	-1.35	-5.31	-0.24	-3.41	-5.51
24c	HDPE	600	1/4 plate	17.5	10,500	1.5	-3.52	-0.07	Not tested	0.22	-4.06
29a	HDPE	200	1/4 plate	20	4,000	3.0	-3.31	-3.14	3.25	-3.38	-4.86
29b	HDPE	300	1/4 plate	20	6,000	3.0	-1.52	-5.69	-0.33	-3.73	-5.26
34a	Steel	200	1/4 plate	20	4,000	0.75	-2.92	-4.30	-5.63	-3.17	-5.36
34b	Steel	300	1/4 plate	20	6,000	0.75	-2.25	-1.29	-1.52	-1.12	-7.00
39a	Steel	200	1/4 plate	20	4,000	1.5	-2.89	-4.30	-5.11	-4.00	-4.81
39b	Steel	300	1/4 plate	20	6,000	1.5	-2.94	-1.63	-1.70	-1.13	-6.73
44a	Steel	200	1/4 plate	20	4,000	3.0	-2.80	-4.47	-5.77	-3.53	-4.95
44b	Steel	300	1/4 plate	20	6,000	3.0	-3.03	-1.81	-2.05	-1.48	-6.15

***Table 13** – Error of measurement test results when testing all meters with and without the presence of air or sediment*

Test No.	Pipe material	Pipe size (mm)	Disturbance	Air flow rate (m^3/h)	Upstream length (nD)	Upstream length (mm)	Velocity (m/s) ± 0.1	EUT				
								A	B	C	D	E
45	PVC	200	None	0	20	4,000	1.5	-2.73	-4.79	1.79	-3.86	-3.64
46a	PVC	200	Air flow	1	20	4,000	1.5	-3.61	0.39	1.99	-3.48	-2.22
46b	PVC	200	Air flow	2.5	20	4,000	1.5	-4.81	Not tested	1.15	-4.40	-5.04
46c	PVC	200	Air flow	5	20	4,000	1.5	-3.96	0.48	2.29	-3.61	-3.91
46d	PVC	200	Air flow	10	20	4,000	1.5	-98.41	1.04	1.97	-100.00	-54.34
46e	PVC	200	Air flow	20	20	4,000	1.5	-100.00	1.52	-100.00	-100.00	-100.00
47a	PVC	200	None	0	20	4,000	0.75	-2.27	-6.05	2.22	-5.24	-3.55
47b	PVC	200	Sediment	0	20	4,000	0.75	-2.05	-4.50	-0.10	-4.34	-16.75
47c	PVC	200	None	0	20	4,000	1.5	-2.73	-4.79	1.79	-3.86	-3.64
47d	PVC	200	Sediment	0	20	4,000	1.5	-8.10	-9.46	-6.51	-7.81	-14.70
47e	PVC	200	None	0	20	4,000	3.0	-6.48	-5.19	2.11	-6.00	-4.36
47f	PVC	200	Sediment	0	20	4,000	3.0	-5.65	-11.89	-0.50	-9.55	-16.42

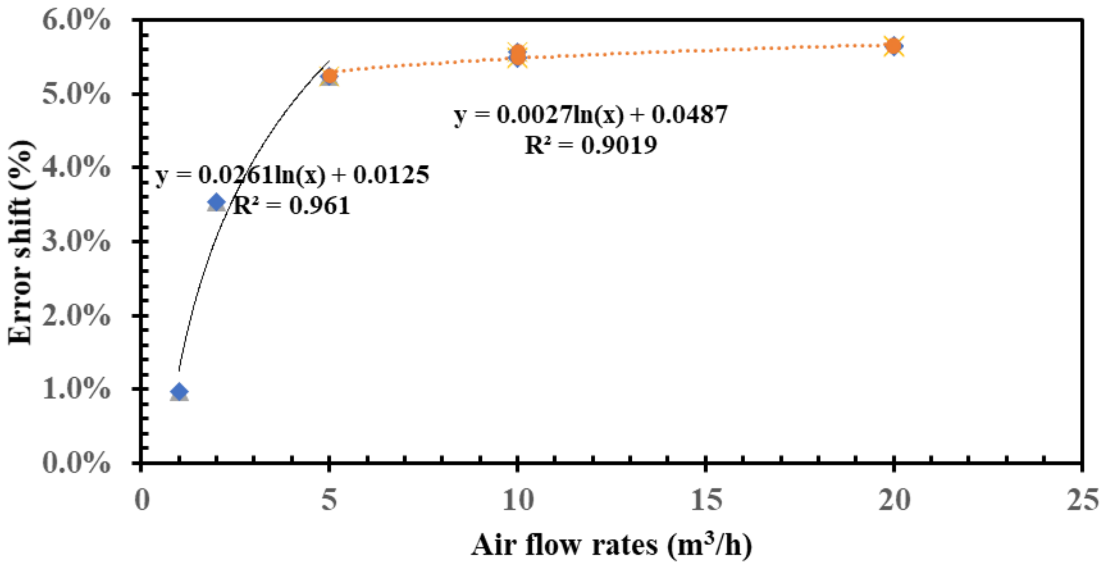

Figure 22 *– Correlation between the presence of air at various flow rates and error shift values (%) for AFMG reference flow meter*

6. References

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