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1 INTRODUCTION AND OBJECTIVES

The purpose of this document is to present the uncertainties of the X-Ray Fluorescence (XRF) Vx Spectra 29 multiphase flowmeter obtained during the series of tests performed in 2023 at the Singapore Well testing Centre (SWTC) multiphase flow loops facility.

This document was prepared specifically to demonstrate the typical XRF Vx Spectra 29 performances under controlled conditions and reasonably short recording time. The results presented herein are derived from the increasing experience of the Vx technology as more and more flow-loop tests are performed since the commercialization of the new product.

This document will present the data used and analysis method applied to determine the specifications before showing the results and performances.

2 METHOD

The performance specifications are determined by analysis of flow loop measurements within the required GVF (Gas volumetric flow rate divided by total volumetric flow rate at line conditions) and line pressure ranges.

For each acquired flow period (i.e. a given flow conditions set on the flow loop), the deviation (absolute and relative) from the Vx meter computed rates versus the loop reference is calculated. This generates a distribution of deviations from which the percentage falling within a particular limit can be calculated. The convention in the multiphase metering business is to present the performance within a 95% confidence interval. This means if a large number of data “ND” is recorded then 95% of them should be within the given claimed specification (usually ND should be larger than 250 for each defined range). This is described by a normal distribution.
Some statistic tool (calculation of the standard deviation, binomial law…) allows establishing for each output parameter (total mass, liquid, gas, WLR, and WVF) the correct target value and pass/no pass criteria.

Meanwhile, with the new product on the market, the number of data collected in each GVF and Pressure ranges is not large enough (i.e. ND <<250), it is then necessary to correct the mathematical standard deviation by a factor which is depending of the ND number, this correction is based on the well-known analysis using Student’s Distribution which correct for this lack of data and associated bias. Student's Distribution is a tool capable to estimate the mean of a normally distributed population in situations where the sample size (ND) is small and population standard deviation is unknown. It can be seen as describing a subset from a full test (Large ND); as such the Student’s distribution is related to ND and, and larger is ND and more the distribution resembles a normal distribution.

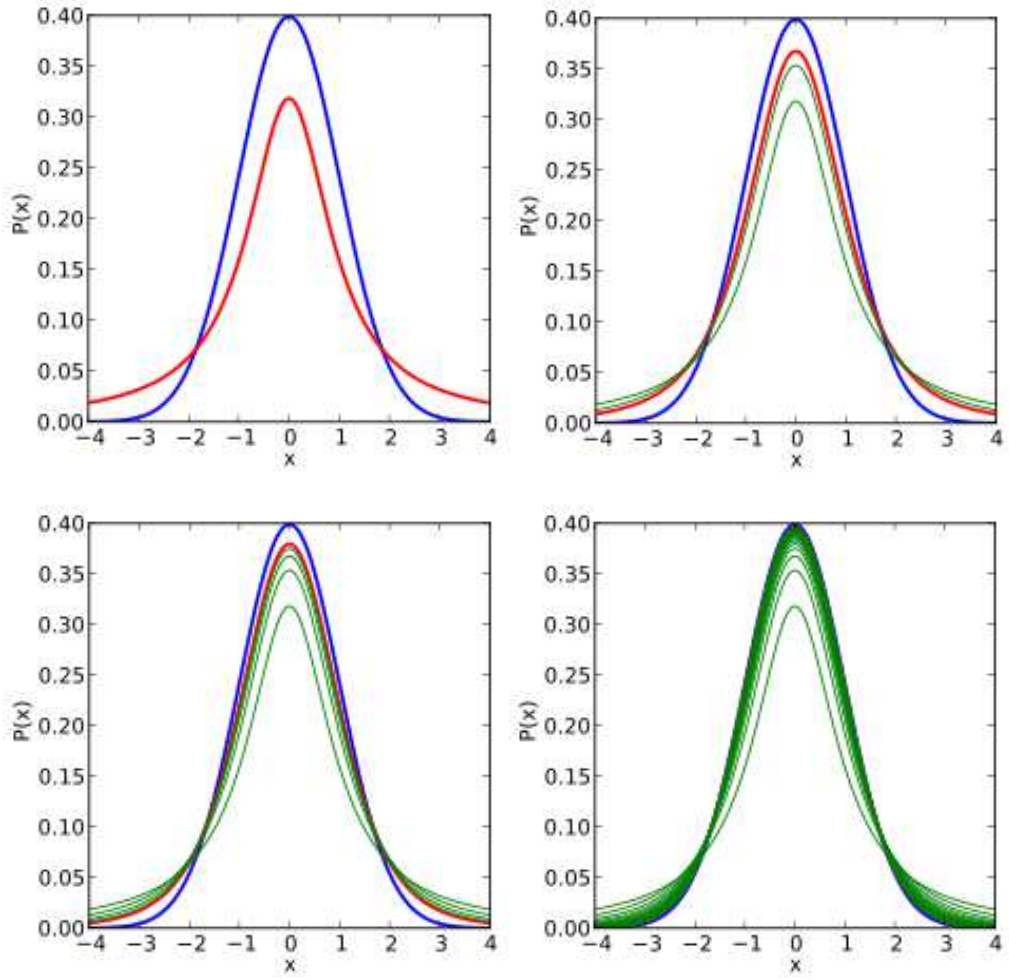

Figure 1: Top left, in blue the normal distribution and in red for a very small value of ND the Student's distribution, Top right the same info with in green the previous value and now ND slightly larger, bottom left a much larger sample (ND bigger) represented with the red color, on the bottom right (large sample) the red line is converging with the blue line representing the normal distribution.

The analysis combines more than 650 test points for all GVF ranges from 0 to 100%, and in general with different pressure ranges below 30 bara at throat conditions and presented inside the working envelope in the Figure 2. The operating envelope of the given meter size, represented on Figure 2 by the black line, is defined by the differential pressure limits over which accurate flow measurements as stated in this document are obtained.

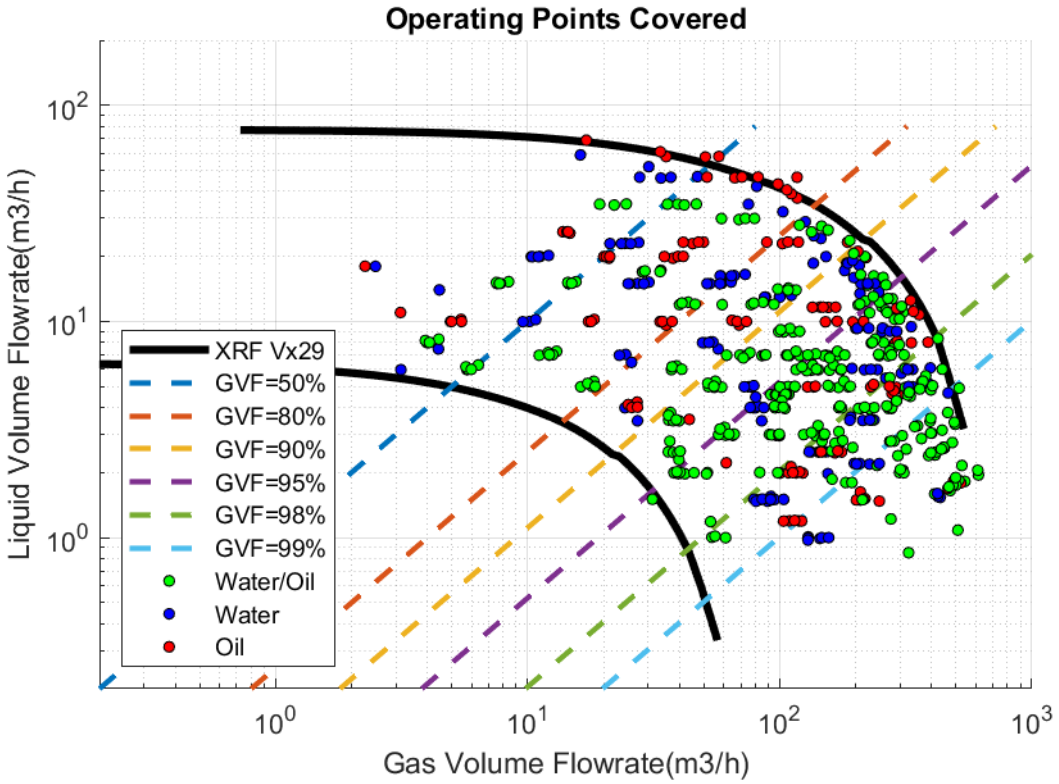

Figure 2: Data collected inside the meter working envelope (in black)

The same data presented in the Figure 2 are now plotted inside the composition map of WLR versus GVF in the Figure 3 and Figure 4. These tests cover a wide range of three phase flowing conditions and flow rates, essentially covering the entire composition map (i.e. ratios) of the XRF Vx Spectra 29 meter.

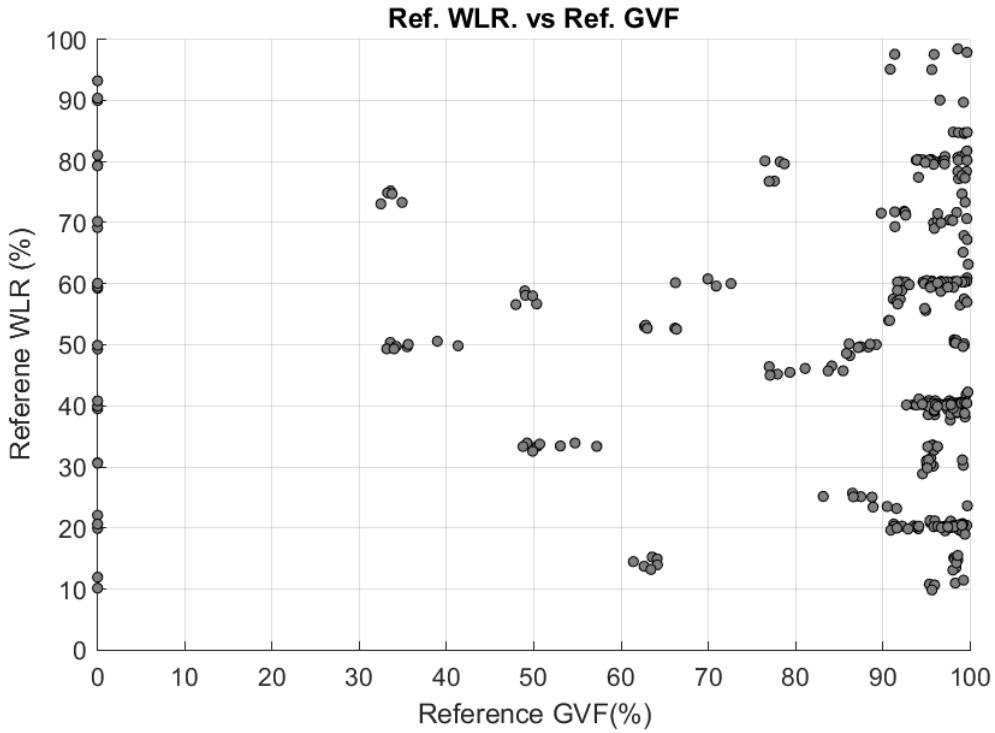

Figure 3: Composition map (WLR vs. GVF) of test points for GVF:0-100%

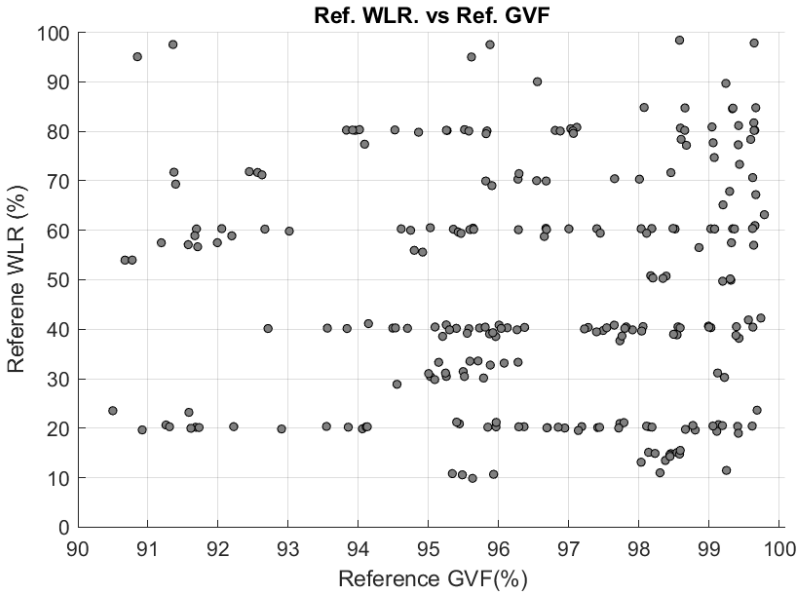

Figure 4: Composition map (WLR vs. GVF) of test points for GVF>90%

The analysis was performed for several combinations of pressure ranges and GVF ranges, grouped over ranges. The results are presented for relative and absolute liquid & gas rates, absolute water/liquid ratio (WLR) and water volume fraction (WVF).

3 TYPICAL METER SPECIFICATIONS

The typical specifications of the meter were obtained from several test campaigns prior to those validation tests and are as below:

XRF Vx Spectra 29 Performance (95% confidence level)		Unit	Gas Volume Fraction GVF					
		[%]	0-20	20-90	90-95	95-98	98-99	99-100
Mass	Relative	[%]	3.1		3.1	3.3		
	Absolute	[kg/s]	0.2					
Liquid	Relative	[%]	2.5		3.5	7.4	10	-
	Absolute	[m^3/h]	-	-	-	0.6		
WLR	Absolute	[%]	1.5	2.0	2.0	3.5	6.5	-
WVF	Absolute	[%]	-	-	0.45	0.45	0.25	0.15
Gas	Relative	[%]	-	8.0	8.0	11	11	
	Absolute	[m^3/h]	2.5	-				

** At GVF below 20%, an absolute uncertainty of 2.5 am^3/h is considered due to the low quantity of gas.

NOTE: "When absolute and relative uncertainties values are stated for one given parameter, at specific GVF range, the value to select must be the greater one when converted to absolute uncertainty."

Table 1: XRF Vx Spectra 29 Typical Performance

4 ANALYSIS

Typical analysis study and representation of the data is shown below in relative and absolute deviation for the main output parameters leading to the performance established in the Table 1.

4.1 Total Mass Flow Rate Deviation

The meter is primarily measuring the total mass flow rate which is conserved whatever the line pressure and temperature. This is a quality indicator of the performance of the meter reference system, the deviation should lesser than 3-4% relative or way below 0.2kg/s for absolute.

XRF Vx Spectra 29 Performance (95% confidence level)		Unit	Gas Volume Fraction GVF		
		[%]	0-90	90-95	95-100
Mass	Relative	[%]	3.1	3.1	3.3
	Absolute	[kg/s]	0.2		

NOTE: "When absolute and relative uncertainties values are stated for one given parameter, at specific GVF range, the value to select must be the greater one when converted to absolute uncertainty."

Table 2: XRF Vx Spectra 29 Typical Performance for Mass Flowrate

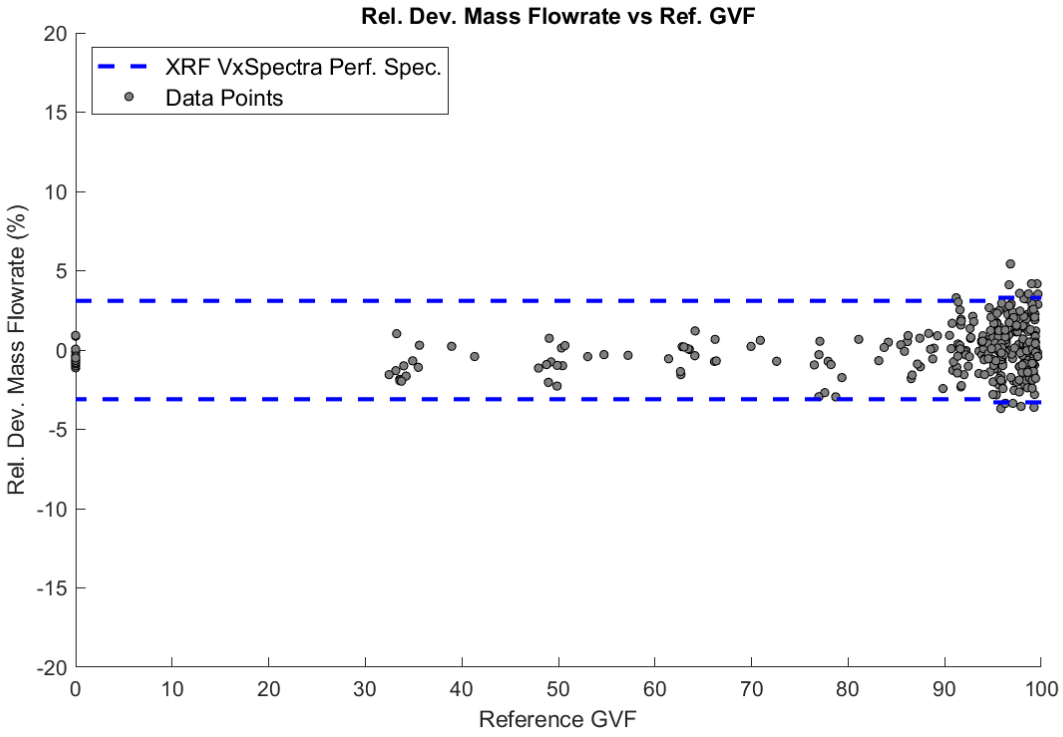

Figure 4a: Relative deviation plot for total mass flow rate, GVF:0-100%

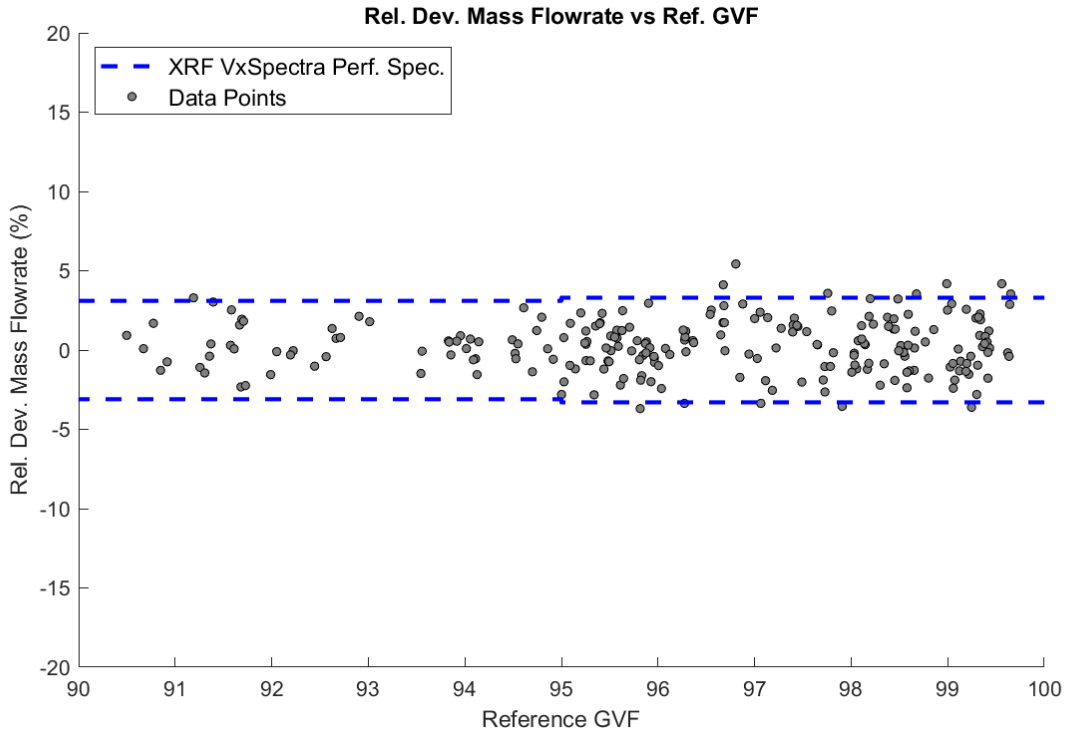

Figure 4b: Relative deviation plot for total mass flow rate, GVF:90-100%

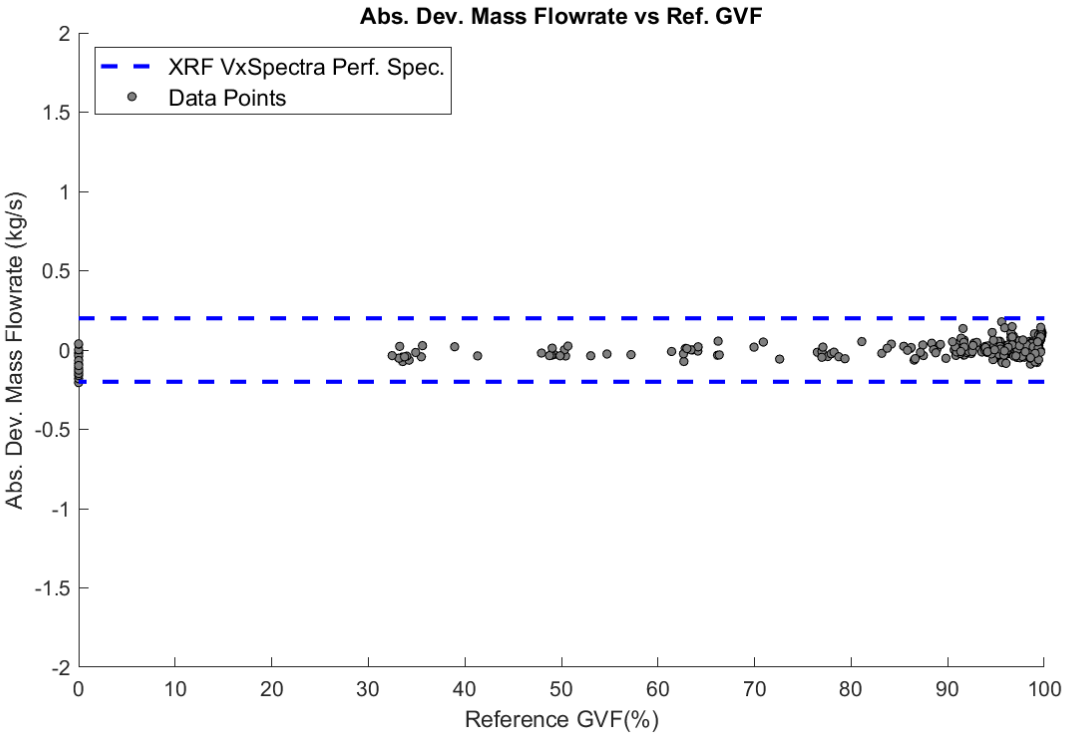

Figure 5: Absolute deviation plot for total mass flow rate

4.2 Liquid Rate Deviation

The following table presents the liquid volume rate relative and absolute deviation for different GVF ranges.

XRF Spectra 29 Performance (95% confidence level)		Unit	Gas Volume Fraction GVF					
		[%]	0-20	20-90	90-95	95-98	98-99	99-100
Liquid	Relative	[%]	2.5		3.5	7.4	10	-
	Absolute	[m^3/h]	-	-	-	0.6		

NOTE: "When absolute and relative uncertainties values are stated for one given parameter, at specific GVF range, the value to select must be the greater one when converted to absolute uncertainty."

Table 3: XRF Vx Spectra 29 Typical Performance for Liquid Flowrate

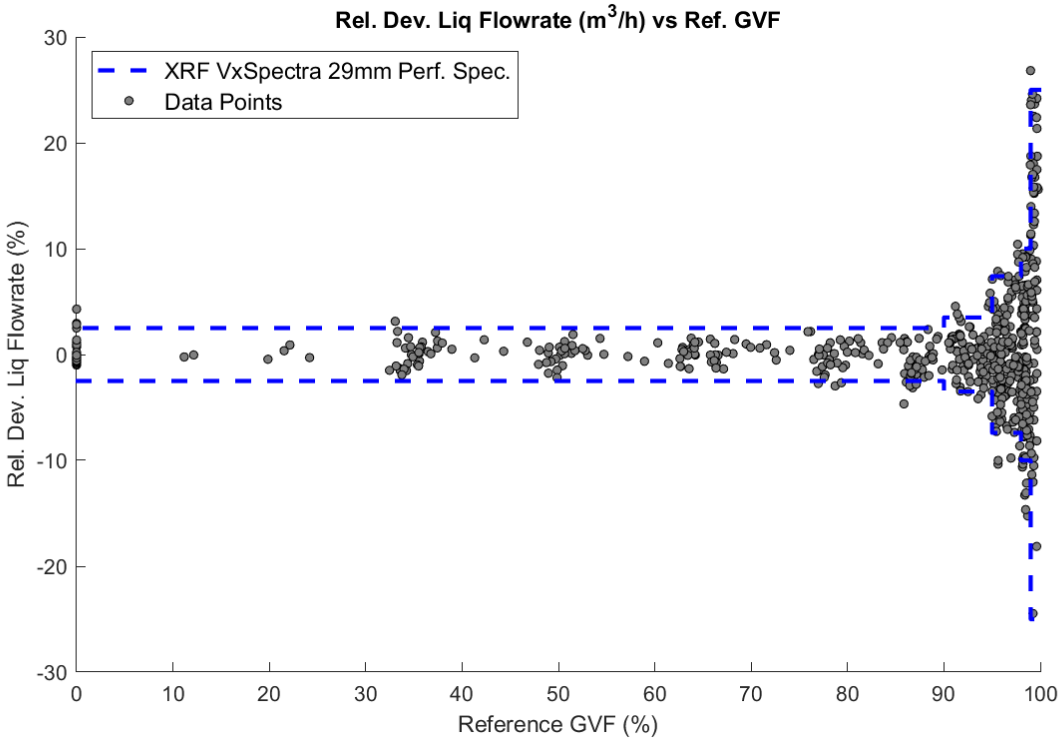

Figure 6a: Relative deviation plot for liquid rate, GVF:0-100%

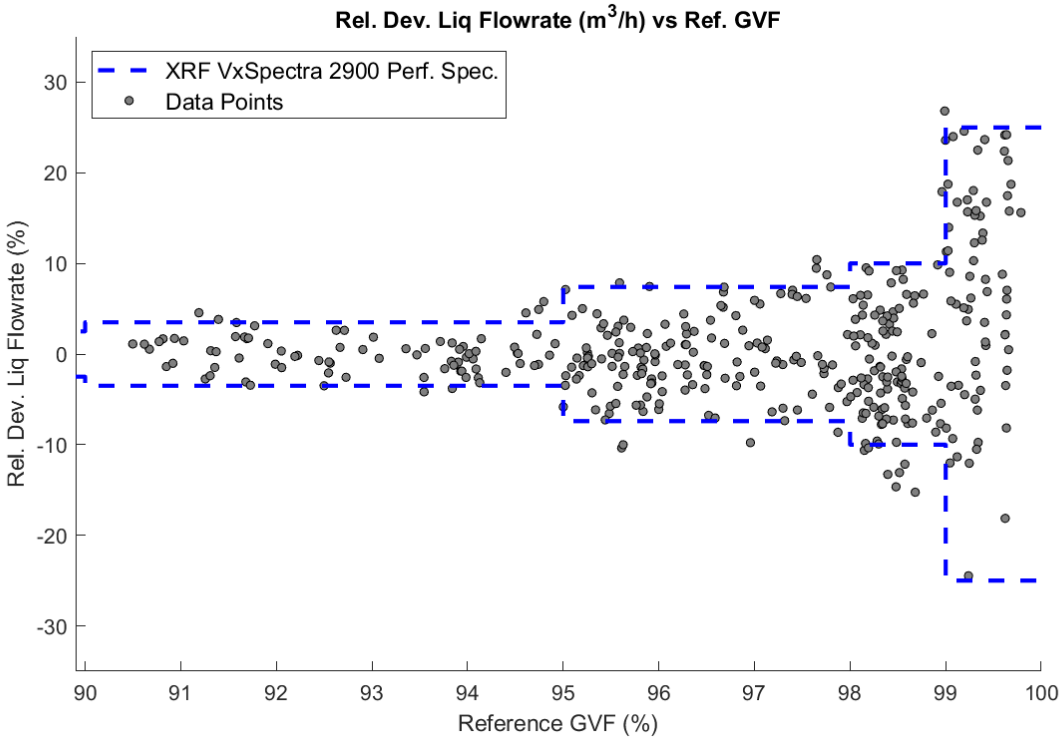

Figure 6b: Relative deviation plot for liquid rate, GVF:90-100%

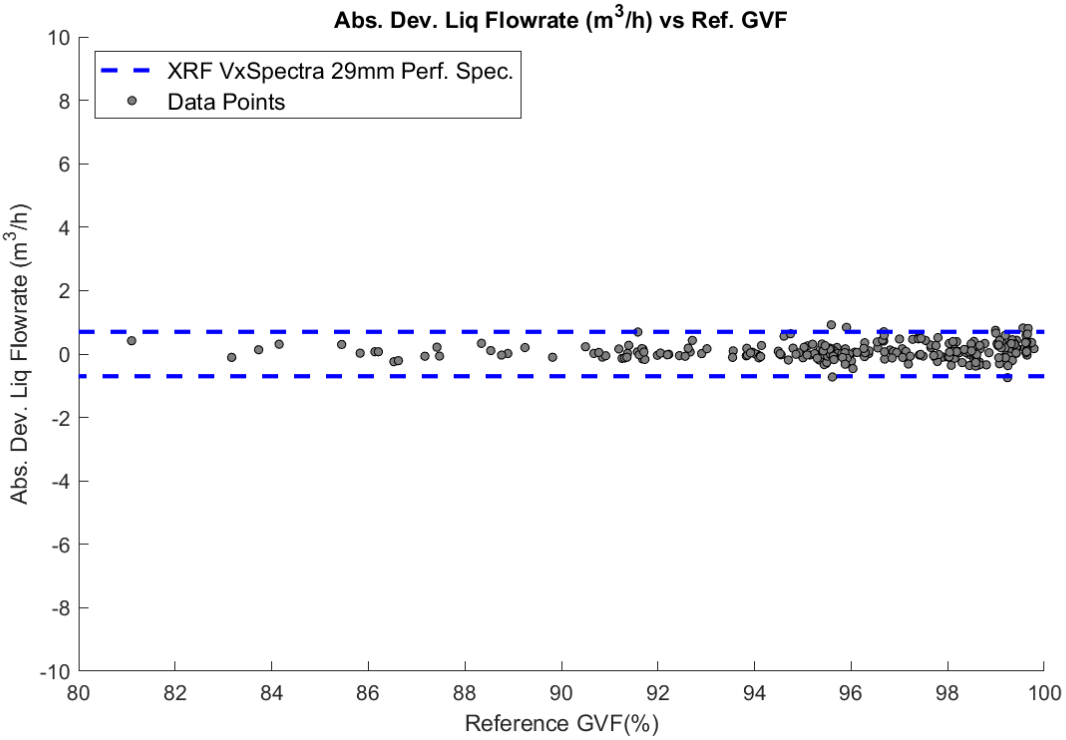

Figure 7: Absolute deviation plot for liquid rate

4.3 Gas Rate Deviation

The following presents the gas rate relative deviation.

XRF Vx Spectra 29 Performance (95% confidence level)		Unit	Gas Volume Fraction GVF					
		[%]	0-20	20-90	90-95	95-98	98-99	99-100
Gas	Relative	[%]	**	8.0	8.0	11	11	-
	Absolute	[m^3/h]	2.5	-				

** At GVF below 20%, an absolute uncertainty of 2.5 am3/h is considered due to the low quantity of gas

NOTE: "When absolute and relative uncertainties values are stated for one given parameter, at specific GVF range, the value to select must be the greater one when converted to absolute uncertainty."

Table 4: XRF Vx Spectra 29 Typical Performance for Gas Flowrates

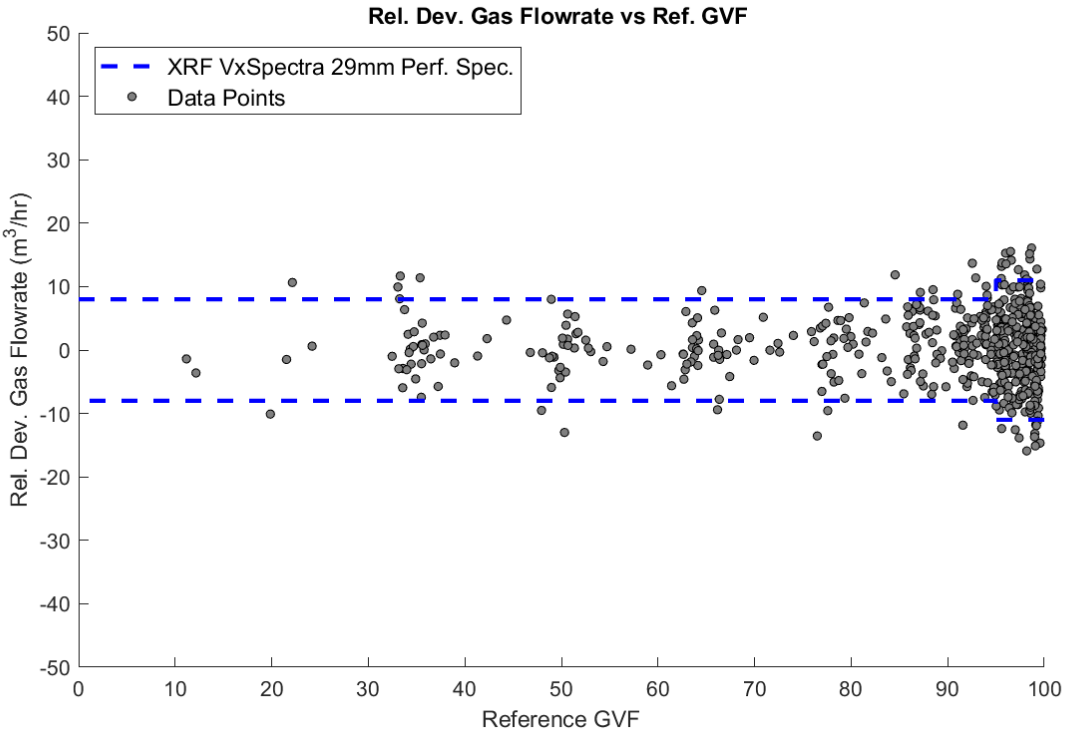

Figure 8a: Relative deviation plot for gas rate, GVF:0-100%

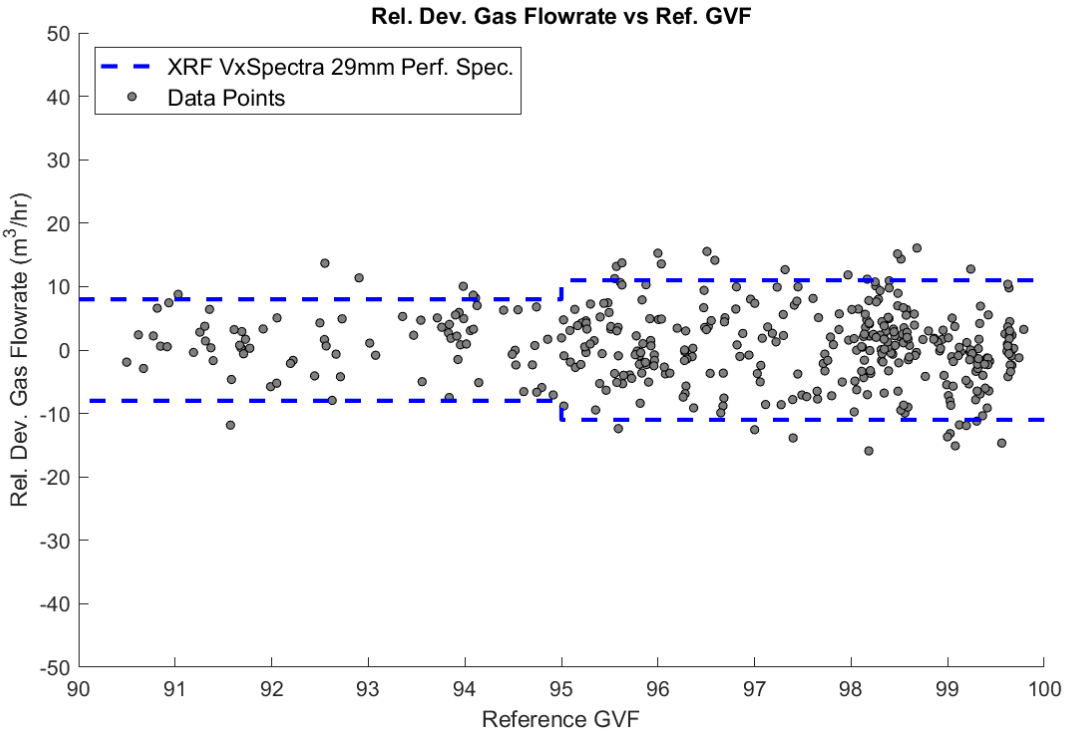

Figure 8b: Relative deviation plot for gas rate, GVF:90-100%

At low operating GVF, the relative uncertainty has little meaning (reaching infinity for conditions with no gas) and absolute uncertainty is instead considered.

4.4 Water Liquid Ratio Deviation

The following table presents the water liquid ratio absolute deviation. At very high GVF or Wet Gas conditions (usually GVF above 98%), it is the Water Volume Fraction (WVF is defined by the Water flow rate divided by total flow rate) which is considered (see section 4.5).

XRF Vx Spectra 29 Performance (95% confidence level)		Unit	Gas Volume Fraction GVF					
		[%]	0-20	20-90	90-95	95-98	98-99	99-100
WLR	Absolute	[%]	1.5	2.0	2.0	3.5	6.5	-

NOTE: "When absolute and relative uncertainties values are stated for one given parameter, at specific GVF range, the value to select must be the greater one when converted to absolute uncertainty."

Table 5: XRF Vx Spectra 29 Typical Performance for WLR

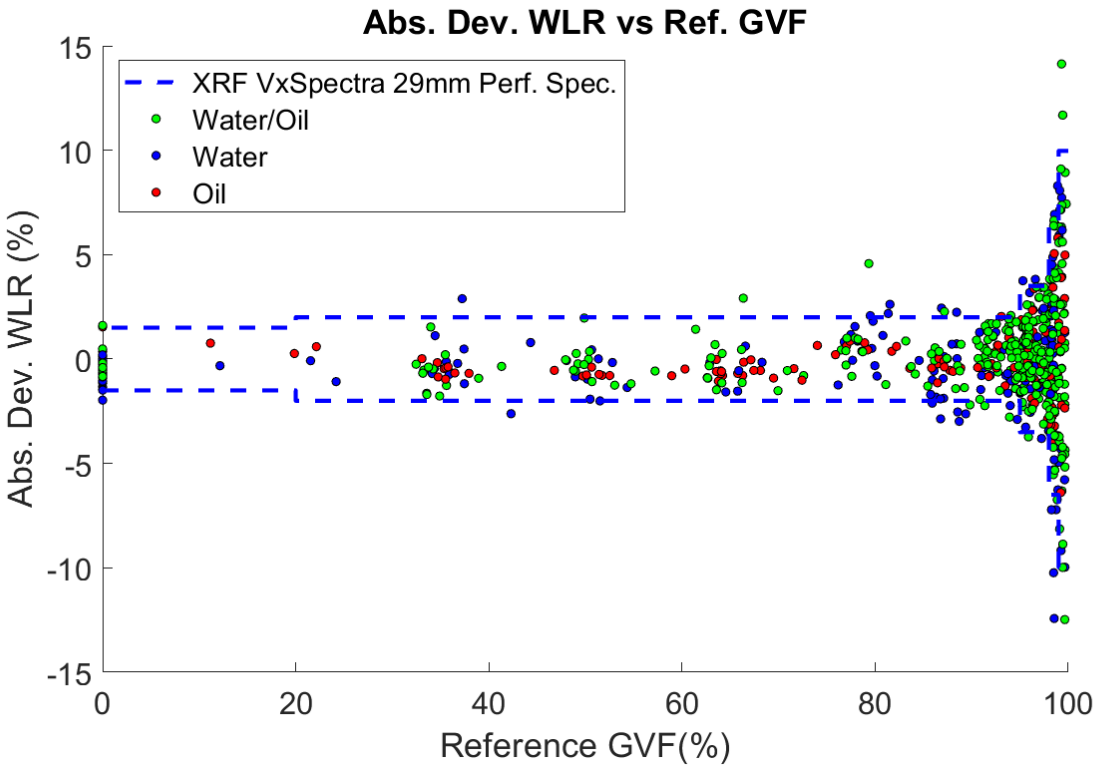

Figure 10a: Absolute deviation plot for water liquid ratio, GVF:0-100%

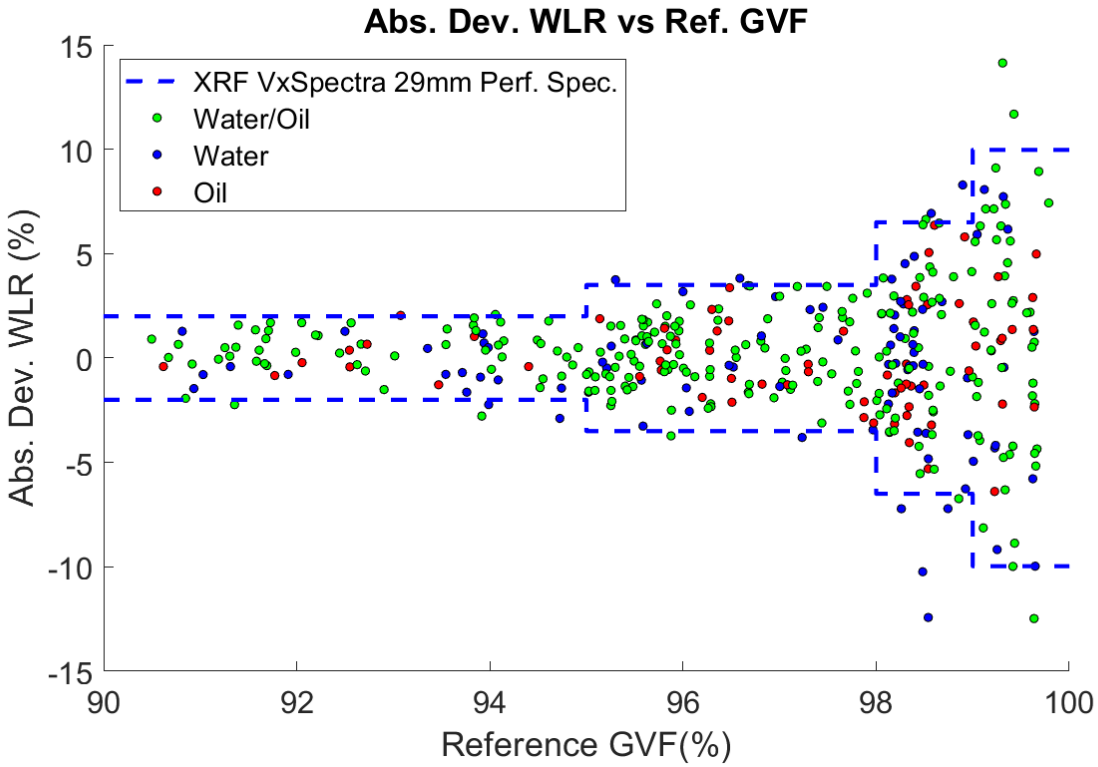

Figure 10b: Absolute deviation plot for water liquid ratio, GVF:90-100%

4.5 Water Volume Fraction Deviation

The following table presents the water/liquid ratio absolute deviation in different GVF ranges.

XRF Vx Spectra 29 Performance (95% confidence level)		Unit	Gas Volume Fraction GVF					
		[%]	0-20	20-90	90-95	95-98	98-99	99-100
WVF	Absolute	[%]	-	-	0.45	0.45	0.25	0.15
	Absolute	[ppm]	-	-	4,500	4,500	2,500	1,500

NOTE: "When absolute and relative uncertainties values are stated for one given parameter, at specific GVF range, the value to select must be the greater one when converted to absolute uncertainty."

Table 6: XRF Vx Spectra 29 Typical Performance for WVF

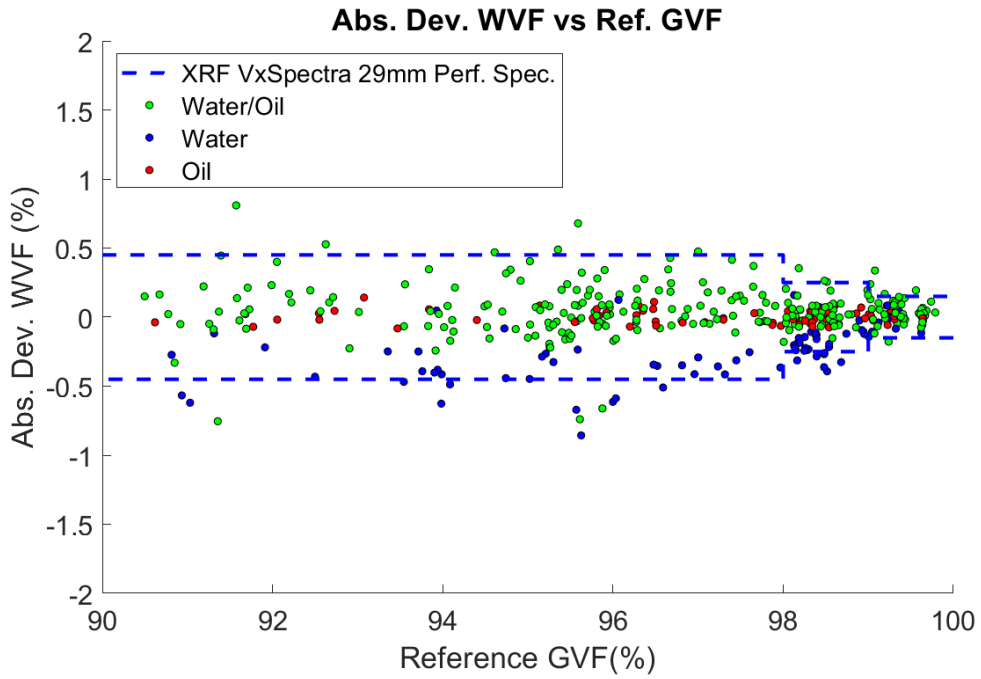

Figure 11: Absolute deviation plot for water volume fraction, GVF:90-100%

5 CONCLUSIONS

This validation was performed according to industry-wide metrological standards and statistical analysis methods. The metrological performance as presented in this document established by exposing an XRF Vx Spectra 29 to an extensive round of tests covering a wide range of flow conditions in terms of flow rates and flowing fractions, and pressure. The acquired test data demonstrates the measurement robustness, independently from test fluids, flow regimes or operating conditions.

6 REFERENCES

1. GEMS 102793279 *Vx Spectra 29 Metrological Performance*

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CONDITIONS

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CONDITIONS

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