First-ever validation of a multiphase flow meter on extensive ranges of GVF (0-100%), WLR (0-100%), Pressure (4-30 bar), and flow regimes from stable to unstable in a well-controlled flow loop facility.

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INTRODUCTION

Multiphase flowmeter is believed to be out of its infancy now, and it has been expected to be used in any type of conditions (GVF, WLR, and Pressure Range). However, the dream to have one meter capable to address all conditions and flow regimes seems to be still on. The aim of this paper will be to answer the persistent questions that arise: "Why should we use this multiphase flow meter rather than the other one? Does it work for brown and green field? Can we use the same multiphase technology for the next 20 years? How is it possible to verify it?"

For the best multiphase flowmeters, a drastically improvement has been done over the years and it is not reaching flow rate relative error within 2-3% in some cases. In the meantime, the number of flow loops around the world with a low uncertainty measurement is very limited and to validate above statement it requires flow loop uncertainty within 1% maximum.

In parallel, multiphase metering experts have been capable to challenge the different technologies on the market over the year through JIP (wet gas or multiphase), and found some blind spots where most of the multiphase meters are working badly or with serious limitation (low pressure (between 4-15 Bara), unstable flow regime). It is also true that the demonstration of the performance of Water Liquid Ratio (not to confuse with Water Fraction) is extremely challenging at high GVF for any technology. Furthermore, the WLR is usually challenged in the extreme case where there is either little water or oil present in the main flow, or in the transition band from oil to water continuous.

From a business point of view, it should be highlighted that typical well production around the world is at low pressure (<20 bara) even for gas well to reduce the cost of the pipeline and additionally, in mature field the GVF is high, with WLR close to 100% for brownfield or close to 0% for green field. Therefore, it is a large population of wells that in general multiphase flowmeters cannot properly handle yet.
Indian Customer engaged in development of brown field with similar conditions (as mentioned above) had planned to add some Unmanned Well Platforms to augment its production. Customer had awarded an EPC contract to well-known EPC Company in India for the construction of unmanned platform wherein Multiphase meter was part of the tender.

Customer requirement was to have a multiphase flow meter to measure the individual phase flow rates of crude oil gas and water in the well fluid and other associated parameter as per process design criteria with intended accuracy in all flow regimes for well testing purpose in lieu of the test separator. Knowledge of the individual fluid flow rates of a producing well is required to facilitate reservoir management, field development, operational control, flow assurance, and production allocation.

MPFM was used for well testing in lieu of Test Separator, for the following reasons:

o To overcome operational hindrances due to frequent maintenance of equipment and associated instruments.
o To reduce man-hour efforts during well testing.
o Quicker well testing procedures.
o To cut cost on well testing.

Customer had very tight performance expectation in terms of gas, liquid flow rate and WLR performance in WET GAS conditions from 90 to 99.x% GVF with only two phases flowing through the meter either Gas-Oil or Gas-Water as per specifications (95% confidence interval) given below:

Fluid/ Parameter	GVF Range (%)	Typical Performance Specification (%)
Gas	< 90	10
	> 90	5
Liquid	< 60	5
	60-98	10
	> 98	No Spec.
WLR	< 90	2.5
	90-98	5
	> 98	No Spec.

Table 1: Vx flow meter performance specifications

As per the tender requirement, EPC Company can procure multiphase meter only from the approved vendors with an assurance from vendor of proving the technology in 3rd Party flow loop as Blind Test.

EPC Company had contacted all approved vendors for evaluation. Under Evaluation EPC Company was convinced that Schlumberger-India can demonstrate the performance of the meter in 4- 30 Bara pressure range with GVF from 0 to 100%, and WLR from 0 to 100%.

INITIAL REQUIREMENT & CHALLENGES

Initial requirement as per the datasheet provided by client is given in Table 2 hereafter:

	Min	Avg	Max
Total Liquid Rate (Blpd)	100	1100	3000
Oil Flow rate (Bopd)	40	300	1750
Water Flow rate (Bwpd)	10	800	2700
Total Produced Gas Flow rate (k SCMD)	16	47	170

Table 2: Flow Rate expected over the years from wells.

And a prepared matrix as per the requirement is given below in Table 3:

	Platform Conditions			BLPD	SCMD
S. No	Liq	Gas	WLR	Qliq	Qgas sc
1	Min	Max	100	100	170000
2	Min	Min	95	100	16000
3	Min	Max	95	100	170000
4	Min	Min	90	100	16000
5	Min	Max	90	100	170000
6	Min	Min	10	100	16000
7	Min	Max	10	100	170000
8	Min	Min	0	100	16000
9	Min	Max	0	100	170000
10	Max	Max	100	3000	170000
11	Max	Min	95	3000	16000
12	Max	Max	95	3000	170000
13	Max	Min	90	3000	16000
14	Max	Max	90	3000	170000
15	Max	Min	10	3000	16000
16	Max	Max	10	3000	170000
17	Max	Min	0	3000	16000
18	Max	Max	0	3000	170000

Table 3: Matrix as per the Flow rates expected.

Enquiry about the capability of flow loops around the world to achieve these requirements was made, but none of the flow loops could meet all of them. All flow loops working conditions either were narrow in terms of Pressure, GVF requirements or in WLR range irrespective of the flow rates. The Matrix was then amended and is given in Table 4 below:

	Platform Conditions			BLPD	SCMD
S. No	Liq	Gas	WLR	Qliq	Qgas sc
1	Min	Max	100	500	170000
2	Min	Min	95	800	30000
3	Min	Max	95	500	170000
4	Min	Min	90	800	30000
5	Min	Max	90	500	170000
6	Min	Min	10	800	30000
7	Min	Max	10	500	170000
8	Min	Min	0	800	30000
9	Min	Max	0	500	170000
10	Max	Max	100	3000	170000
11	Max	Min	95	3000	75000
12	Max	Max	95	3000	170000
13	Max	Min	90	3000	75000
14	Max	Max	90	3000	170000
15	Max	Min	10	3000	75000
16	Max	Max	10	3000	170000
17	Max	Min	0	3000	75000
18	Max	Max	0	3000	170000

Table 4: Modified Matrix as per the Flow loop

With the revised requirements, once again, all the flow loops were contacted but the requirements were such that only two flow loops could be used under certain limitation, however due to the test expected in winter season only one was capable to answer the need. Further iterations based on the replies from NEL and the customers, led to have agreed on a modified t matrix that can be achieved on the NEL UK facilities. Additionally, the National Engineering Laboratory is considered one of best flow loops around the world and recognized by a large amount of our customer for the metrology accuracy. Measuring a complete range required by client was really a tough task for NEL but they took the challenge of these versatile conditions to meet (Ref [1-3]). The finalized Matrix for Multiphase and Wet Gas flow loops is given in Table 5 & 6 below:

Sr. No	Q oil l/s	Q water l/s	Q liq l/s	Q gas l/s	Est. Press.
	m3/h	m3/h	m3/h	m3/h	Bar
1	8.16	0.16	30	19.44	4.3
2	6.66	1.66	30	19.44	5.0
3	5.00	3.33	30	19.44	3.7
4	3.33	5.00	30	19.44	3.5
5	1.66	6.66	30	19.44	5.0
6	0.00	8.33	30	19.44	3.1
7	10.88	0.22	40	25.93	3.7
8	8.88	2.22	40	25.93	4.3
9	6.66	4.44	40	25.93	5.0
10	4.44	6.66	40	25.93	4.3
11	2.22	8.88	40	25.93	5.0
12	2.22	8.88	40	25.93	3.7
13	0.00	13.88	50	32.41	3.5
14	11.11	2.77	50	32.41	5.0
15	8.33	5.55	50	32.41	3.1
16	5.55	8.33	50	32.41	3.5
17	2.77	11.11	50	32.41	5.0
18	0.00	13.88	50	32.41	3.1
19	16.33	0.33	60	38.89	3.5
20	13.33	3.33	60	38.89	5.0
21	10.00	6.66	60	38.89	3.1
22	6.66	10.00	60	38.89	3.5
23	3.33	13.33	60	38.89	5.0
24	0.00	16.66	60	38.89	3.1

Table 5: Final Multiphase flow loop matrix

NEL proposed to use for the first time both facilities (Multiphase and Wet Gas Flow loops) with the same meter over 2 consecutive weeks of test and target the Wet Gas conditions initially with Oil & Gas and then a week later with Water & Gas. This was the second times in the life of this flow loop to be done. This requires massive work to flush and clean correctly the facility.

Sr. No	Press. (bar)	Qgas lc (m3/h)	Qliq (m3/h)	Medium Type
1	12	208.33	0.66	Water
2	12	208.33	0.66	Oil
3	12	590.28	0.66	Water
4	12	590.28	0.66	Oil
5	12	208.33	35.42	Water
6	12	208.33	35.42	Oil
7	12	590.28	35.42	Water
8	12	590.28	35.42	Oil
9	30	100.00	0.66	Water
10	30	100.00	0.66	Oil
11	30	236.11	0.66	Water
12	30	236.11	0.66	Oil
13	30	100.00	35.42	Water
14	30	100.00	35.42	Oil
15	30	236.11	35.42	Water
16	30	236.11	35.42	Oil

Table 6: Final Wet Gas flow loop matrix

NEL Multiphase Flow Loop Description

The NEL UKAS accredited multiphase facility is based around a 3-phase separator, which contains the working bulk fluids. The oil and water are re-circulated around the test facility using two variable speed pumps. For safety reasons nitrogen is used as the gas phase and can be delivered at up to 0.25 kg/s by evaporation of liquid nitrogen on demand. The delivery pressure of the nitrogen is up to 12 Bara (absolute pressure) at the injection point. However, at the measurement section several tenths of meter away, the pressure is already down to 3-5 Bara After passing through the test section, the nitrogen is exhausted to atmosphere from the separator.

The test section can accommodate test setups of up to 60m horizontal and 12m vertical. The standard test section is constructed in 4-inch schedule 40 pipework. Piping and adaptors are available to allow testing of 2, 3, 4, and 6-inch meters. The standard flange rating is ANSI class 150, but many other sizes can also be accommodated. The facility is manufactured entirely from stainless steel and can thus utilize brine substitutes and dead crude oils as the working fluids in addition to de-ionized water and refined oils. Perspex visualization sections are available in 2, 4, and 6-inch pipe sizes.

Test fluids used in our application was a black oil to mimic "as much as we can" real conditions:

- A mixture of Forties, Beryl and Oseberg crude oil, topped to remove light ends and increase the flashpoint above 65°C, with kerosene substitute (Exxol D80) added to restore the original viscosity (Approximately 30° API gravity)
- An aqueous solution of Magnesium Sulphate of concentration 80g/l (based on $MgSO_4.7H_2O$).

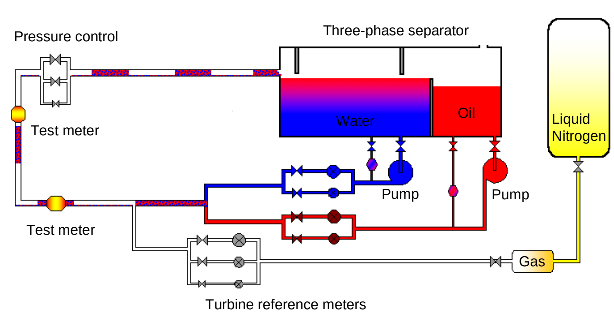


Figure 1: Schematic of NEL Multiphase Flow Facility

The NEL High Pressure Wet Gas Test Facility Description

The High-pressure wet gas test facility at NEL is based around a 6-inch nominal bore flow loop. A schematic diagram of the nominal facility arrangement for wet-gas tests is provided in Figure 2. Although nominally 6-inch diameter, the two parallel test sections can accommodate line sizes ranging from 4 inch through 10 inch. The gas used for testing is oxygen free nitrogen supplied by BOC in 230 bar gauge cylinder banks. The facility operate at a nominal temperature of 18 deg C over a nominal pressure range of 10 to 63 bar gauge, which corresponds to a gas density range of 12.76 to 74.54 kg/m3. The operating temperature has an oil density of 804.4 kg/m3 and a dynamic viscosity of 2.21 mPa.s, and salt free water with a nominal density of 1000.2 kg/m3 and a dynamic viscosity of 1.04 mPa.s. As the kerosene substitute is the standard liquid used in the test facility its physical properties are relatively stable over time, while with water the density and viscosity have to be measured each time it is used for high accurate reference measurement.

Referring to Figure 2 below, the gas is driven around the flow loop by a 200 kW fully encapsulated gas blower. In wet-gas operation, the gas is drawn from the gas-liquid separator outlet by the blower, and is then cooled using chilled water supplied shell and tube heat exchanger. The gas passes through the reference flow meter and then on into the selected test line, where it mixes with the operating liquid at the liquid injection point. The liquid stream temperature is also controlled using a chilled water supplied shell and tube heat exchanger, located upstream of the liquid pump. The gas and the liquid stream temperature are controlled to within +/- 0.1 deg C. The gas flow rate is controlled by varying the speed of the blower, while the liquid flow rate is controlled by using the isolation valves at the end of the injection line.

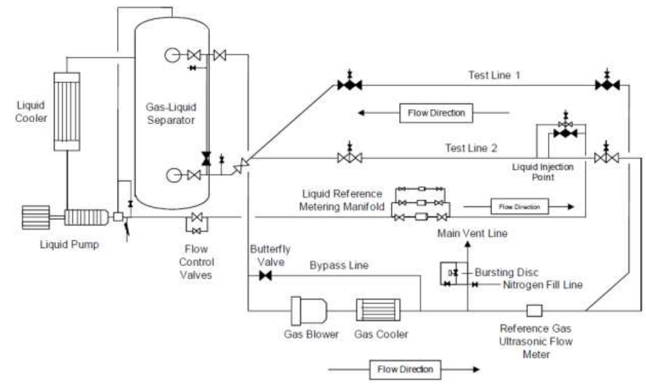


Figure 2: Schematic Diagram of the NEL Wet-Gas Test Facility.

The gas reference volumetric flow rate is measured using a calibrated 6-inch Daniel Seniorsonic model 3400 gas ultrasonic flow meter range of 100 m3/h to 1500 m3/h. The liquid reference volumetric flow rate is measured using one of three available turbine meters, of sizes ½-inch, 1-inch and 3- inch sizes, which cover a nominal flow rate range of 0.2 to 90 m3/h. All static pressure, differential pressure and temperature measurements are taken using traceable calibrated instrumentation.

TEST SET-UP AND PROCEDURES

Meter Setup at Multiphase facility

As per the tender requirement, a Bureau Veritas (BV) Inspector was appointed by EPC Company to audit the test procedure followed.

An empty pipe calibration was performed after installation of radiation source and electrical connections. A sample of the NEL multiphase facility oil together with fluid property data was given to set the meter correctly and was used to calculate mass-absorption reference data for the oil phase.

The PhaseWatcher Vx52 multiphase flow meter was supplied with a blinded tee inlet. The Vx meter and tee connections were adapted to the test facility standard 4” class 150 via crossovers and the meter installed in vertically upward flow.

After setting the meter and to quantify the level of uncertainty between the system Flow loop – Multiphase flow meter, a ‘blind’ test of monophasic flow gas was done stating the overall discrepancy, then after a test was carried out over a range of multiphase flow conditions as supplied inside Table 5 (first in oil and gas; then a week later in water and gas).

Figure 3: View Showing PhaseWatcher Vx52 Meter Installation in Test Section at Multiphase Loop

Meter Setup at Wet Gas Loop Facility

Vx PhaseWatcher multiphase meter was installed and tested in Test Line 2 of the NEL high-pressure wet gas test facility. A 6-inch schedule 40 bore camera spool was installed between the liquid injection point and the Vx flow meter, to allow the monitoring of the liquid hold up level in the two-phase horizontal pipe flow.

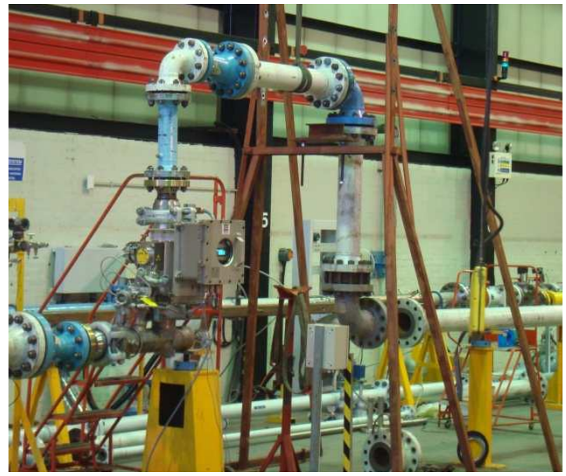


Figure 4: View Showing PhaseWatcher Vx52 Meter Installation in Test Section at Wet Gas Flow Loop

Test Procedure

Test points from the agreed test matrix were selected by the NEL Facility Engineer in the order, which best suits the facility operational efficiency and the need from the end user. The reference flow conditions were then set and left to stabilize. A test point was logged once the NEL Engineer was satisfied that the required flow condition had been achieved and was stable enough and this was confirmed to be stable by the Vx Engineer. Data logging was carried out for the flow condition as per agreed Matrix (to try to mimic in the best manner the conditions met in the field). The NEL facility control computer and the PhaseWatcher Vx52 data acquisition flow computer clocks were synchronized prior to testing. Logging of the reference and test meter data was initiated simultaneously with the TUVNEL engineer and both systems loggings terminated automatically after the prescribed test period.

TEST RESULTS

The agreed test matrix is given in Table 1.

Multiphase Facility Flowrates							
Matrix	l/s	l/s	l/s	%	l/s	l/s	%
Number	Qoil	Qwater	Qliq	W/C	Qgas	Qtot	GVF
1	8.17	0.17	8.33	2	19.44	27.78	70
2	6.67	1.67	8.33	20	19.44	27.78	70
3	5.00	3.33	8.33	40	19.44	27.78	70
4	3.33	5.00	8.33	60	19.44	27.78	70
5	1.67	6.67	8.33	80	19.44	27.78	70
6	0.00	8.33	8.33	100	19.44	27.78	70
7	10.89	0.22	11.11	2	25.93	37.04	70
8	8.89	2.22	11.11	20	25.93	37.04	70
9	6.67	4.44	11.11	40	25.93	37.04	70
10	4.44	6.67	11.11	60	25.93	37.04	70
11	2.22	8.89	11.11	80	25.93	37.04	70
12	0.00	11.11	11.11	100	25.93	37.04	70
13	13.61	0.28	13.89	2	32.41	46.30	70
14	11.11	2.78	13.89	20	32.41	46.30	70
15	8.33	5.56	13.89	40	32.41	46.30	70
16	5.56	8.33	13.89	60	32.41	46.30	70
17	2.78	11.11	13.89	80	32.41	46.30	70
18	0.00	13.89	13.89	100	32.41	46.30	70
19	16.33	0.33	16.67	2	38.89	55.56	70
20	13.33	3.33	16.67	20	38.89	55.56	70
21	10.00	6.67	16.67	40	38.89	55.56	70
22	6.67	10.00	16.67	60	38.89	55.56	70
23	3.33	13.33	16.67	80	38.89	55.56	70
24	0.00	16.67	16.67	100	38.89	55.56	70

Table 7: Multiphase Flow loop; Actual Test Conditions Logged for Vx52 Multiphase Flowmeter.

NOTE: Test points were not necessarily conducted in the order given above, but again were instead carried out in the most suitable order for facility operational efficiency.

NEL Test Point No.	Reference Gas Pressure (bar abs)	Reference Gas Volumetric Flow Rate (m^3/h)	Reference Liquid Volumetric Flow Rate (m^3/h)	Reference Gas Volume Fraction (%)
1	30.2	235.9	0	100
2	30.0	100.1	0	100
3	29.9	235.8	0.66	99.72
4	29.9	119.5	0.95	99.21
5	30.5	236.6	35.36	87.00
6	30.3	119.9	51.09	70.13
7	12.6	589.6	0	100
8	12.5	208.2	0	100
9	12.8	589.8	0.65	99.89
10	12.6	207.9	0.66	99.68
11*	13.1	315.7	19.06	94.31
12	13.1	205.1	35.31	85.31

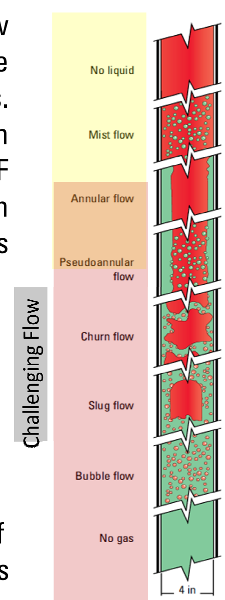
*data logging time of 1800 seconds used.

Table 8: Wet Gas Flow loop: In the order taken with Vx52 Flow Meter with Kerosene as the Liquid Phase.

NEL Test Point No.	Reference Gas Pressure (bar abs)	Reference Gas Volumetric Flow Rate (m^3/h)	Reference Liquid Volumetric Flow Rate (m^3/h)	Reference Gas Volume Fraction (%)
1	30.5	236.1	0	100
2	30.4	100.7	0	100
3	30.4	236.3	0.67	99.72
4	30.4	119.3	0.98	99.18
5	31.2	235.6	35.32	86.96
6	31.0	119.4	51.05	70.06
7	20.3	249.4	0	100
8	20.5	252.0	7.52	97.10
9	20.5	181.0	7.51	96.02
10	20.8	248.4	20.23	92.47
11	20.7	179.7	20.18	89.90
12	12.5	591.7	0.65	99.89
13	12.2	206.8	0.67	99.68
14	12.7	269.3	16.23	94.32
15	12.7	196.7	31.34	86.26
16	12.3	593.0	0	100
17	12.2	207.2	0	100

Table 9: Wet Gas Flow loop: In the order taken, for the Vx52 Flow Meter with Water as the Liquid Phase.

Multiphase Flow Loop Results:



The tests for the multiphase flow loop were chosen to be in the most challenging conditions. Indeed the flow regime is stable in the very high GVF or very low GVF (i.e. mist flow or bubble flow can be considered as homogeneous flow). At the contrary, in medium GVF (~60 to ~80) and line pressure between 3.5 and 5 Bara, it is the worst conditions with some severe intermittent flows typically slug and plug flow and where we wanted to demonstrate the performance of the meter. Additionally, multiples claims over the years have been made that no multiphase flowmeters work in this type of conditions with low pressure.

Volumetric flow rates measured by the reference gas meters have been converted to the pressure and temperature conditions as reported at the PhaseWatcher to permit a direct comparison at line conditions. Figures 6, 7, 8 & 9 illustrate the performance of the Vx multiphase flow meter during the test program with respect to the performance specification given in table 1. The graphs show the Vx meter liquid, gas and water cut measurement capabilities with respect to reference GVF.

Figure 5 shows the mass flow performance with respect to GVF. The error bands displayed on this graph are for guidance only and do not form part of the meter performance specification.

As mentioned, earlier these conditions were very challenging and the level of accuracy expected was high. Permanent audit of the current ongoing measurement was done by NEL; to ensure the best comparison and avoid any bias in the interpretation. Even after the test, some test points such as 21 and 22 from the test matrix were found to be beyond the limits of stability expected for liquid water cut conditions over the 30-minute test period and then they were rejected in the final report.

Some analysis in real-time allowed a repeat of some flow period such as the points 17, 24 and the best of the repeat and the first measurement has been reported.

Mass Flow Performance

In any comparison test the main parameter to look at is the mass flow rate, this is the ONLY parameter not pressure and temperature dependent, this means that a direct comparison can be done between two equipments as soon as it is the same flow that is passing through both of them (time to flow from one device to the other needs to be taken into account in the practical situation), in our case the distance was small enough and then the recording time was selected to be able to reduce the uncertainty due to this time shift. Figure 5 shows the error between both equipments indicated total mass flow plotted against reference GVF for the PhaseWatcher Vx52 multiphase flowmeter. The uncertainty bands displayed is for guideline, does not represent any specification, and are included for guidance only.

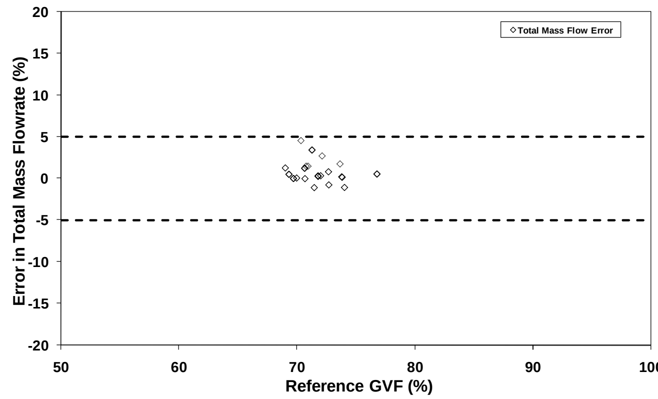


Figure 5: Error in Meter-Indicated Mass Flow Rate versus Reference GVF for PhaseWatcher Vx52 Meter

The total mass flow errors show a mean offset of 0.79% and a standard deviation of 1.37% in very unstable flow and low pressure, this is a very good achievement. It should be noted that the error between both equipments is also inline with the uncertainty claimed for each of the devices that are within 1-1.5%.
Translated in absolute error, the discrepancy between both equipments is within 0.25 kg/s!

Liquid Flow Performance

Figure 6 shows the liquid flow rate error plotted against the reference GVF for the PhaseWatcher Vx52 multiphase flowmeter. The uncertainty bands displayed represent the uncertainty specification shown in Table 1. It can be seen from Figure 6 that all points lie well within specification on liquid flow.

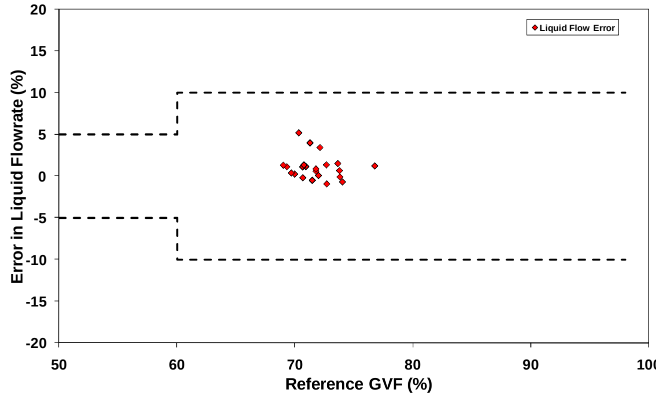


Figure 6: Error in Meter-Indicated Liquid Flow Rate versus Reference GVF for PhaseWatcher Vx52 Meter

In conclusion, the relative error in liquid flow rate collapse in a narrow bandwidth. The liquid flow errors show a mean offset of 1.06% and a standard deviation of 1.44% in highly turbulent and unstable flow.

It should be noted that the error between both equipments is also inline with the uncertainty claimed for each of the devices that are within 1-1.5%.

Finally, it should be understood as highlighted later that the WLR has been changed from almost 0% to 100% in this test, and then there is no phase liquid phase distribution dependency and line pressure within 3.5 to 5 Bara.

Gas Flow Performance

Figure 7 shows the gas flow rate error plotted against the reference gas volume fraction for the PhaseWatcher Vx52 multiphase flowmeter. The uncertainty bands displayed represent the uncertainty specification shown in Table 1. It can be seen from Figure 7 that 21 of the 22 test points lie within specification on gas flow.

n this highly sluggy flow conditions flow at very low line pressure (3.5 to 5 Bara), and the gas flow errors show a mean offset of -3.53% and a standard deviation of 4.26%. This is slightly higher than the liquid, and this is not surprising the gas is always a challenging measurement in these on purpose "worst conditions" selected, the uncertainty in the gas reference measurement is slightly higher and within 1.5% minimum in this case.

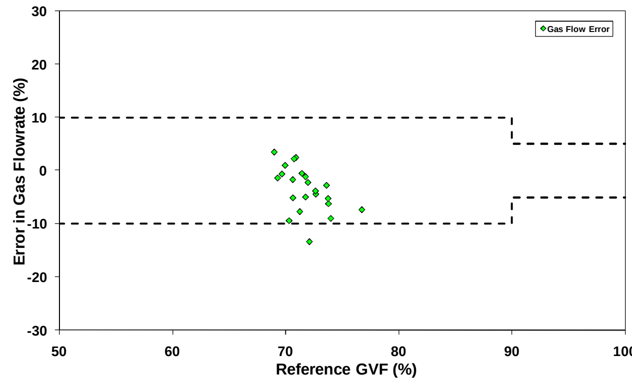


Figure 7: Error in Meter-Indicated Gas Flow Rate versus Reference GVF for Schlumberger PhaseWatcher Vx52 Meter

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Water Cut Performance

Figure 8 shows the error in meter indicated water cut plotted against the reference water cut for the Schlumberger PhaseWatcher Vx52 multiphase flowmeter. The uncertainty bands displayed represent the uncertainty specification shown in Table 1. It can be seen from Figure 8 that all points lie within specification on water cut.

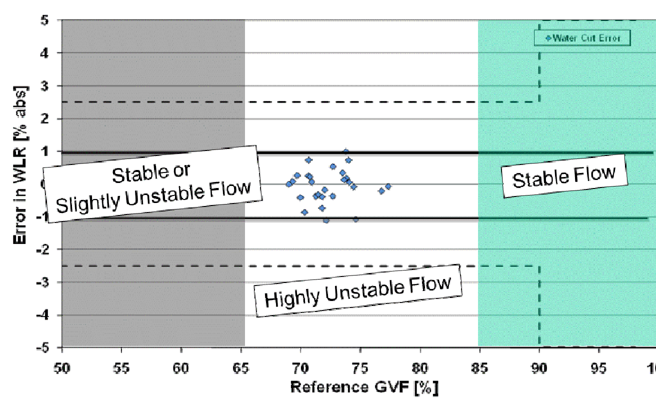

Figure 8: Error in Meter-Indicated Water Cut versus Reference GVF for Vx52 Meter

It is found that the mean offset is around 0.01% and a standard deviation of 0.54% in this low pressure (3.5 to 5 Bara) and very unstable flow.
Most interesting is the display of the same data versus WLR and not GVF as presented below

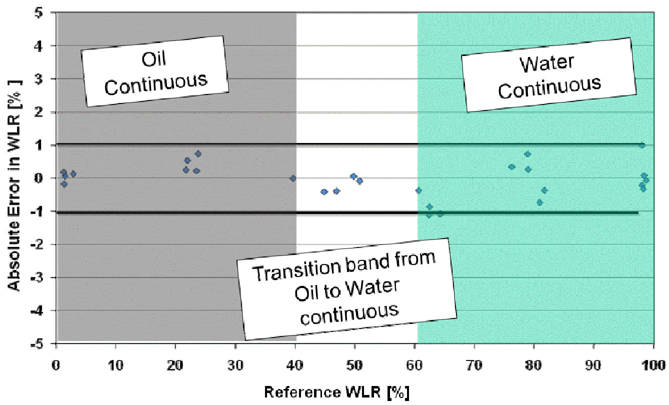

Figure 9: Error in Meter-Indicated Water Cut versus Reference WLR for Vx52 Meter

It is interesting to note that whatever the mix of oil and water the WLR is not sensitive to the inversion point nor to the phase continuous. This should show one of the strength of the gamma ray measurement. Furthermore, the slugging conditions do not affect the uncertainty in the WLR measurement.

Wet Gas Flow Loop Results:

The main challenge for the WET GAS Flow loop was to reduce the line pressure as much as possible, the flow flop being designed normally to handle pressure in the range of 20 to 65 Bara. It is well known that if the pressure is higher than higher is the gas density and then easier is the fluid mechanics model to develop (this can be approached from a mass flow rate point of view). Albeit never an exhaustive analysis has been done and published on the reasons the performance are becoming worst versus lower pressure, it is a fact that all multiphase flow meters or wet gas meters on the market had some (serious or not) challenges to handle low pressure and high GVF. This leads at least to a first general conclusion it is not technology dependent in general but more fluid mechanics dependent. The purpose of this test with the Vx had for purpose to achieve two objectives: first to be much more inline with production where usually the pressure is not extremely high, second from a metrological point of view this is one of the most challenging conditions to have a proper understanding of the fluid mechanics.
It represents then the worst conditions and gives an indication about the robustness in the Vx technology and model developed. The flow loop was also challenged to get the highest liquid loading and up to 30% (or GVF ~ 70%). It should be highlighted the flexibility of the NEL flow loop which was obviously not designed initially for such stretch in the functioning conditions. The pressure was stretch down to 12 for a first series of test and 30 Bara to be more inline with known performance and then be able to do an internal benchmarking.

Mass Flow Performance:

Twenty-seven of the twenty-nine relative data points were within the performance specifications as given in Table 1 over the GVF range of 70-100% and different line pressures used. Four of these twenty-nine points were having unstable gas flow rates at reference measurement and were disregarded for assessment. In conclusion, it can be stated that twenty-four out of twenty-five relative errors obtained from the Vx flow meter were within the performance specifications as given in Table 1 with 95% confidence level.

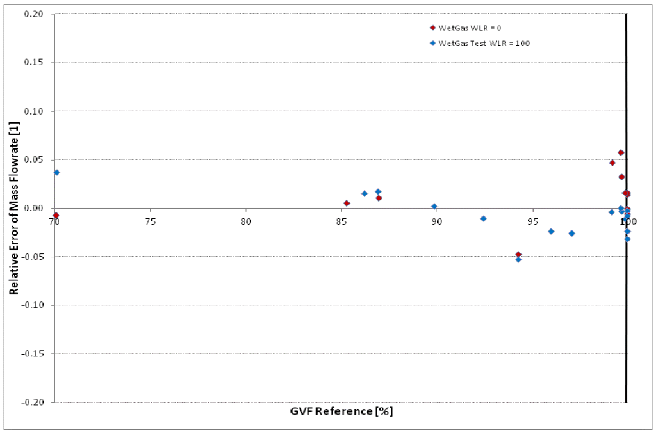

Figure 10: Error in Meter-Indicated Mass Flow Rate versus Reference GVF for Vx52 Meter

The mass flow errors show a mean offset of -0.26% and a standard deviation of 2.55%, which represent in absolute an error in average of less than 0.25 kg/s.

Gas Flow Performance:

Fig 11 shows the gas flow performance of Vx meter until 100%

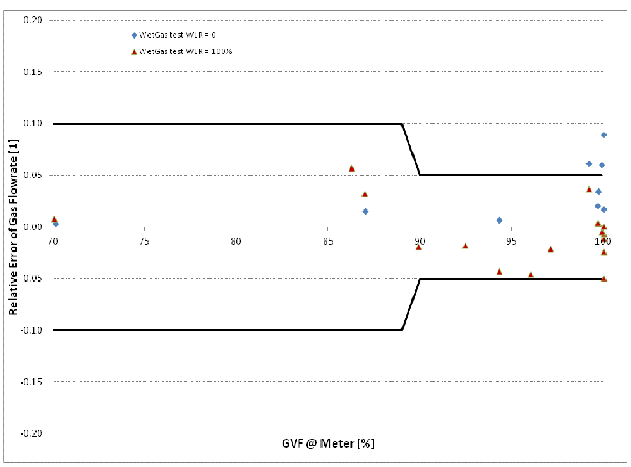

Figure 11: Error in Gas Flow Rate versus Reference GVF from 70 to 100% PhaseWatcher Vx52 Meter.

The Gas flow errors show a mean offset of 0.40% and a standard deviation of 3.34%. It is outstanding performance in this type of pressure from 12 to 30 Bara. It should be noted that in the figure xx, the largest deviation are at 12 Bara, this is where the quantity of gas is also the lowest in mass (~ 1 to 2 kg/s).

Liquid Flow Performance

The relative errors obtained from the Vx flow meter were all within the performance specification as give in Table 1 of +/- 10% over the GVF range of 70-98% at the three test pressures used. Fig 12 shows the graphical presentation of Liquid flow rate performance as per the specifications:

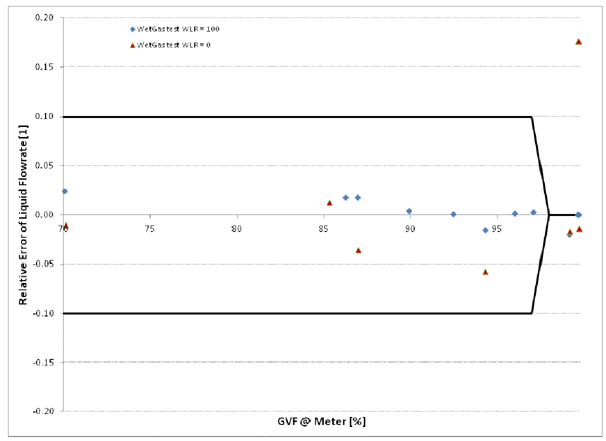

Figure 12: Error in liquid flow rate versus GVF up to 99.5%.

The liquid flow errors show a mean offset of -1.01% and a standard deviation of 2.40%. It is outstanding performance in this range of GVF and pressures.

At Ultra High GVF (>99.5%), it is preferred to give an absolute error which is more meaningful than an relative error and in this case all absolute errors stay within 0.1 m3/h.

WLR Performance

The absolute errors in WLR obtained from the Vx Multiphase Flow meter over the GVF range of 70-98% were within the performance specifications as given in Table 1 at the three pressures used. Fig 13 shows the graphical representation of the WLR Performance as per the specifications:

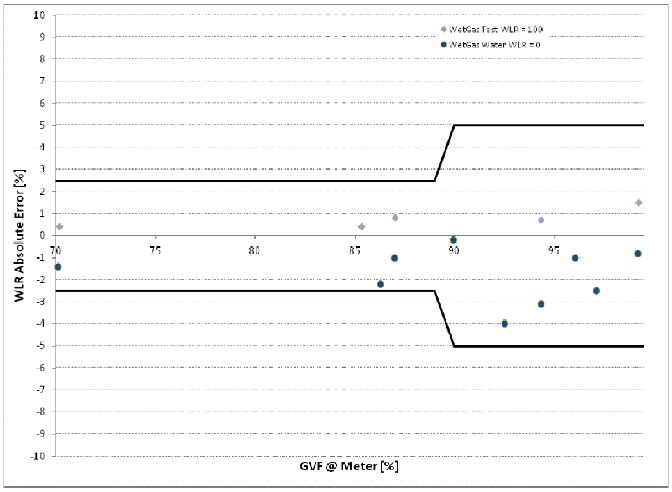

Figure 13: WLR Performance versus GVF up to 99.5% for PhaseWatcher Vx52 Meter

The WLR show a mean offset of -0.90% and a standard deviation of 1.61%. It is outstanding performance in this type of GVF. It can be noticed that the water gas point are better than the oil gas points and this is due to a slight offset in the definition of the oil point. This could be corrected but due to the test in blind mode and with the audit, running this was not possible to change. The reprocessing will have given something within 0.5% mean offset and then a standard deviation within 1.0%

CONCLUSION

This is a first ever test on a same flow lab in wet gas conditions and multiphase conditions in less than a week with the same meter and looking the extreme conditions in terms of flow regimes. Tests have been done from 3.5 Bara to 30 Bara, GVF from 60 to 100% and then WLR from 0 to 100% with multiple intermediate steps including in the inversion zone. This is the most complete investigation done up today, the number of data point is limited due to the time constraint and the flow loop capability which has been used to obtained high quality data. On the top of the already challenging conditions, the selection of the most unstable flow conditions have been made in the case of multiphase flow measurements; in the gas flow conditions it was the lowest pressure achievable on the flow loop which was set, to challenge the metrology of the Vx meter. Finally, the tests were conducted in blind mode, with no multiphase flow for preparation (previous flow or performance analysis) and this was audited by Bureau Veritas during the entire sequence to ensure the quality of the test and a fair demonstration of the performance.

This is unique from the authors' point of view and should be seen as setting a new standard for the multiphase meter demonstration of the performance in future validation tests.

As a reminder, claiming to be able to achieve uncertainty within the range of 1-2% means that the reference of the flow loop needs to be within a third of this target (0.3-0.7%) to comply with standards and then limit the number of flow loop capable to achieve this level. It is not the reference meter that needs to be within the 0.3% but the entire facility, for example double reference measurements with different techniques of measurements are compulsory in order to control if there is contamination of each phase or not. NEL had the only flow loop capable to achieve this range and available at that time, and double reference measurement were used systematically to control if contamination or not where in and then some criteria were put in place to accept or reject in real-time the recording point.

The Vx performance has been presented in details earlier, trying to summarize them with one number, then in what in general people called Multiphase conditions, the standard deviation is within 1% in WLR for most of the GVF range, within 1.5% for the total mass flow rate and liquid rate; and finally 4.3% for the gas rate.

At very and ultra high GVF (in what people call more gassy conditions with pressure from 12 to 30 bara), the mass flow rate being smaller (due to little liquid injected and large amount of gas but at low pressure) the error in the performance is slightly higher and within 2% standard deviation, which is identical for the liquid, the gas flow rate is within 3%, the WLR being within 1.5%

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Finally, we want to thank Jon Arne Huseboe from 3 Phase Measurement who has been a key person to help us to put the meter inline in the best manner, and smoothing all issues of connection at the beginning.

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