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EVALUATION OF A 3” HAIMO FULL RANGE MULTIPHASE FLOW METER

A Report for

Haimo International FZE
PO Box 17256
Dubai
UAE

Project No: HAI007 **Report No: 2014/313** **Date: July 2014**

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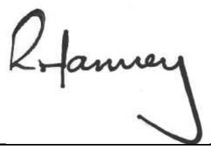
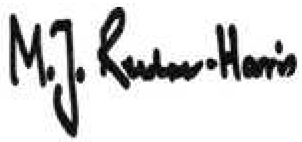
Prepared by:	Approved by:
	
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For
Brian Millington
Director

Date: July 2014

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1 INTRODUCTION

This report presents the results from a flow test programme on a Haimo Full Range multiphase flowmeter (FR MPFM). The aim of this evaluation was to assess the performance of the FR MPFM with respect to the manufacturer's stated specification against a matrix of multiphase flow conditions. The test programme was conducted at the NEL Multiphase Flow Test Facility in East Kilbride, Scotland in May 2014.

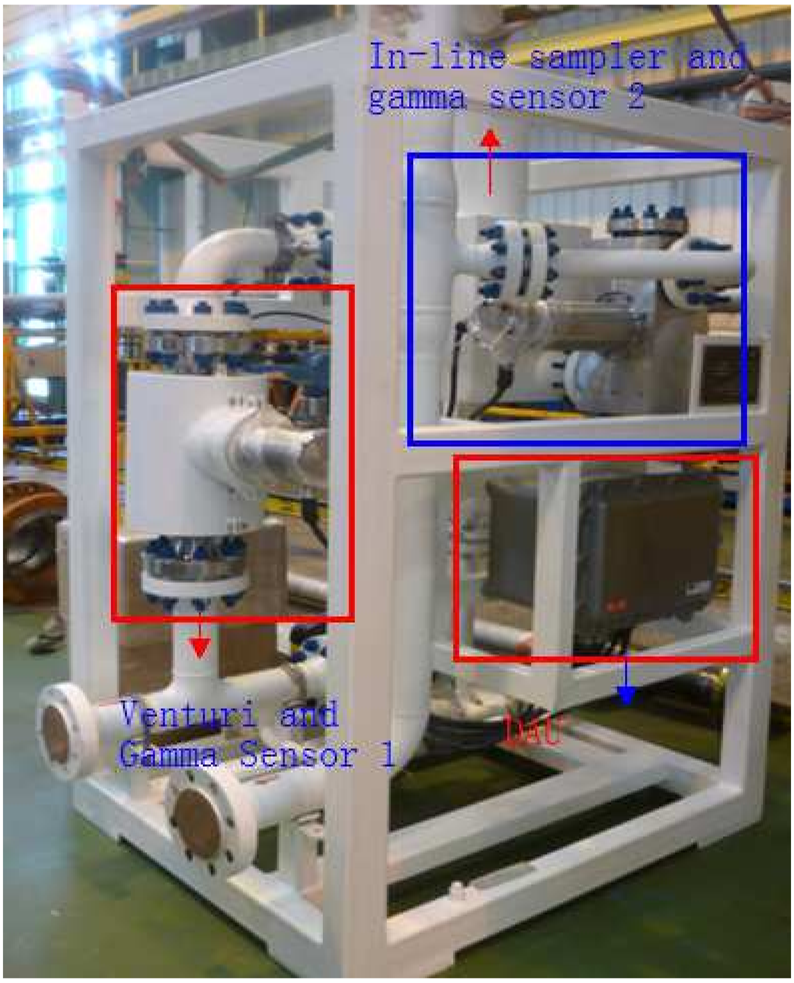

Figure 1 Haimo Full Range MPFM

The Haimo 3-inch Full Range Multiphase flowmeter (FR MPFM) is a compact meter as shown in Figure1, based on a Venturi flow meter, a multivariable transmitter (MVT), in-line sampler and two gamma sensors.

Total flow rate of the multiphase stream is measured by the Venturi flow meter. The MVT collects pressure, differential pressure and temperature data from an appropriate location on the FR MPFM. The raw signals from the MVT are processed by the data acquisition unit (DAU) and used to calculate PVT parameters and flow rates.

There are two gamma sensors in the FR MPFM. Gamma sensor 1 is installed at the throat of the Venturi meter. Gamma sensor 2 is installed downstream of an in-line sampler. The in-line sampler is an innovative design for obtaining a representative liquid sample at high GVF. The GVF of the multiphase stream is measured by gamma sensor 1. When GVF is less than 95%, water liquid ratio (WLR) is also measured by gamma sensor 1. When the GVF is more than 95%, WLR is measured by gamma sensor 2. The pulses from the gamma detector are collected and processed by a new design of high-speed transmitter. The two gamma sensors, high-speed transmitter and in-line sampler combine to provide measurement of WLR and flow rates of liquid and gas over the range 0-100% GVF.

Following installation, the FR MPFM response was characterised over a range of reference multiphase conditions specified by Haimo representatives. A 'blind' test was then carried out over a defined matrix of conditions also supplied by Haimo.

This report describes the NEL Multiphase facility and the test setup as well as data on the performance of the Haimo Full Range multiphase flowmeter at the conditions tested. The NEL facility logged all reference measurements, and the test meter data were acquired via the meter's data acquisition flow computer. The analysis of the data was conducted by comparing averages of the meter and facility parameters logged over the same test period.

Haimo representatives were present for the meter commissioning and for the duration of the testing period.

2 NEL MULTIPHASE FLOW FACILITY

2.1 Layout and Test Fluids

A schematic of the NEL Multiphase Facility is shown in Figure 2. The 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 0.5 kg/s by evaporation of liquid nitrogen on demand. The delivery pressure of the nitrogen is up to 17 bar at the reference measurement location. After passing through the test section, the nitrogen is exhausted to atmosphere from the separator.

The test section can accommodate test setups of lengths up to 60 metres horizontal and 12 metres vertical. The standard test section is constructed in 4-inch schedule 40 pipe work. 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 utilise brine substitutes and dead crude oils as the working fluids in addition to de-ionised water and refined oils. Perspex visualisation sections are available in 2, 4 and 6-inch pipe sizes.

Currently test fluids in use are:

- Paraflex HT 9 refined oil.
- An aqueous solution of Magnesium Sulphate of concentration 96g/l (based on $MgSO_4.7H_2O$).

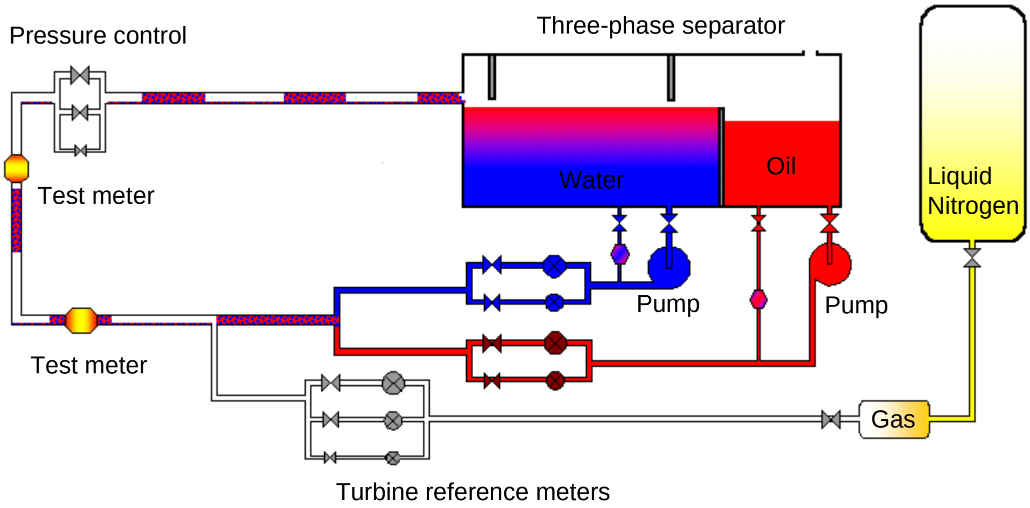

Figure 2 Schematic of NEL Multiphase Flow Facility

2.2 Control

An automated SCADA system allows a single operator to control the entire facility from a PC workstation. The PC is linked to the PLC via an EtherNet which permits a response time from command to action of less than one second. Field instrument data and test instrument information are collected via a separate data acquisition system.

2.3 Separation

At the centre of the facility is a large three-phase gravity separator, which contains approximately 25m^3 of water and 15m^3 of oil. This acts as the storage vessel for the liquids currently under test, in addition to separating the fluids for recirculation. Various devices are employed inside the separator to speed up separation including baffles and parallel plate pack systems. The liquids can be re-circulated indefinitely across much of the operating envelope of the facility; however, at certain high liquid flowrates it is sometimes necessary to shut down to allow the fluids to rest. The level of liquid cross-contamination is continually monitored and the reference liquid flowrates corrected. The separator is equipped with pumps and piping to allow transfer of settled liquids between the water and oil compartments. It is additionally equipped with heat exchangers which allow the temperature of the oil and water to be maintained within ±1°C over the range of approximately 10° to 50°C. Normal operating temperature is 35°C.

3 REFERENCE METERING SYSTEMS

3.1 Flowrate Measurements

The oil and water are separately drawn from the separator and pumped through the oil and water metering circuits respectively. Both metering circuits have a choice of two flowmeters, according to the flowrate required. Oil is metered using Faure Herman helical-blade turbine meters, with the following calibrated ranges:

1¼-inch turbine meter	0.5 to 5.5 l/s
3-inch turbine meter	4.6 to 40.7 l/s

The water is metered using flat-blade turbine meters with the following calibrated ranges:

1½-inch turbine meter	0.5 to 7.9 l/s
3-inch turbine meter	4.8 to 40.1 l/s

The nitrogen is metered through a choice of three gas turbine meters according to the flowrate required. The calibrated ranges of these flowmeters are:

½-inch turbine meter	0.64 to 2.17 l/s
1-inch turbine meter	1.98 to 14.8 l/s
3-inch turbine meter	11.9 to 30.9 l/s

The gas flowrate is measured at the gas supply pressure (typically 17 bar). However, by operating the test section at reduced pressures it is possible to cover the full range of gas volume fractions, with gas superficial velocities up to 20 m/s in the 4-inch test section.

3.2 Cross-contamination Monitoring

An additional bypass stream flows through monitors to measure the cross contamination of the liquid phases. This sample loop is taken from the main pump outlet, passed through a densitometer and returned to the separator. Prior to commencing a test programme clean test fluid samples are drawn from the separator and their densities are categorised over a range of temperatures using an Anton Paar DMA5000 laboratory densitometer. Cross contamination in the sample loops is calculated by:

$$Water\ Cut = (\rho_{indicated} - \rho_{oil}) / (\rho_{water} - \rho_{oil})$$

The water-in-oil content of the oil flow stream and the oil-in-water content of the water stream are determined from an online density measurement using a Parr Scientific vibrating tube densitometer.

3.3 Pressure and Temperature

For accurate volumetric metering of the gas phase, it is necessary to correct for expansion of the gas in the test section, so that the gas volume fraction and gas flowrate at the multiphase meter under test can be calculated. The pressure and temperature of the gas and of the multiphase mixture are therefore measured at a number of locations around the facility:

- At the reference gas meters
- At the inlet to the multiphase test section
- At intervals along the multiphase test section
- At the multiphase meter test location

Volume and, consequently, water-cut corrections are applied to local conditions at the test location.

4 REFERENCE MEASUREMENT QUALITY

4.1 Traceability of Reference Measurements

The instrumentation provided for the facility is of the highest accuracy practicable, and these instruments are calibrated against accurate standards, with a traceable record of the calibrations being maintained.

Most reference instruments are calibrated annually. The oil, water and gas reference turbine meters are calibrated against the UK primary national standard facilities at NEL. The pressure transmitters and platinum resistance thermometers are calibrated against standard equipment held in the multiphase laboratory.

The densities of the separate oil and water phases are also determined off-line prior to a customer's evaluation or test. The fluid densities are determined using an Anton Paar DMA5000 laboratory densitometer and are used in conjunction with the contamination measurement in-line densitometers to correct the reference liquid flow rates for the presence of second-phase contamination. The conductivity of the water phase can be determined using a standard conductivity meter.

4.2 Uncertainty Analysis

It is also important to be aware of the uncertainties which are present in the reference flowrates, taking into account the uncertainties of the calibrated instruments, observed fluctuations in flowrates during tests, and combination of the readings of a number of instruments to give the final values.

The exact uncertainties of a particular reference condition will depend on the values of the individual gas, oil and water flowrates and the ratio between them as well as pressure, temperature and liquid cross-contamination levels.

During 2010 NEL carried out a complete review of the uncertainty of the multiphase flow facility and achieved accreditation for the facility to ISO 17025. NEL is satisfied to quote a combined uncertainty that covers all aspects of the flow measurements including installation and process flow effects for this report. Over the majority of the operating range of the NEL multiphase flow facility the combined uncertainties are:

- Gas flow < 1.5%
- Liquid flow < 1.0%
- Water cut < 1.0% Absolute

One of the most significant contributing factors to the oil and water flowrate uncertainties is the uncertainty in the cross-contamination monitoring. This will lead to the greatest error in oil flowrate at high water cut and the greatest error in water flowrate at low water cut. The biggest contribution to the gas flowrate uncertainty is the test section pressure. The resulting error in gas flowrate is greatest at low test section pressure (which usually occurs when testing at high GVF). However, due to cancellation of errors, the uncertainties in GVF and in total liquid flowrate are much smaller than in the individual component flow rates.

All uncertainties quoted are expanded uncertainties based on a standard uncertainty multiplied by a coverage factor k=2. This provides a level of confidence of approximately 95%.

5 TEST SET-UP AND PROCEDURES

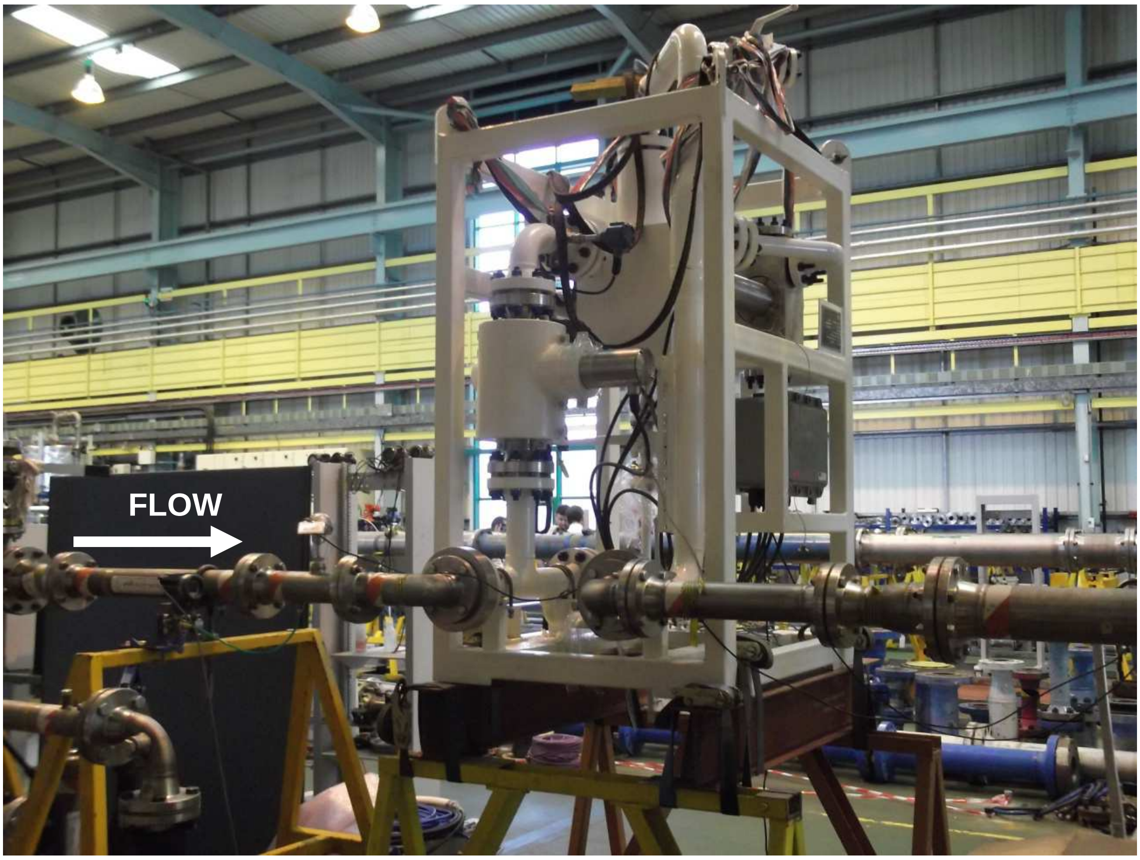

Figure 3 View Showing Haimo Full Range Multiphase Meter Installation in Facility Test Section

5.1 Meter Setup

The Haimo Full Range multiphase flow meter was supplied with 3” Class 600 flanges. All inlet and outlet piping was supplied by NEL to adapt to the facility standard 4” schedule 40 class 150, as shown in Figure 3.

Prior to installation in the test section of the NEL multiphase test facility, the MPFM radioactive sources were installed by Haimo personnel. Data was then gathered on the count rates of the gamma sources with the MPFM measurement sections full of air at atmospheric pressure. The MPFM was then installed in the test section as shown in Figure 3.

Next, the meter was subjected to flowing water at velocities of approximately 0.5 and 2.5 m/s. These flow velocities were repeated using the facility oil phase. A sample of the oil was taken during these tests to check the level of background water content using Karl Fischer titration. The test facility reference instrumentation measured the volume water content in this oil stream at 0.39%, and this compared favourably with the Karl Fischer measurement of 0.54%.

The MPFM performance was then characterised over a range of flow rates as shown in Table 1.

TABLE 1

MPFM CHARACTERISATION MATRIX

3inch Full Range MPFM										
	Liquid		Oil		Water		Gas		BS&W	GVF
No.	m3/h	m3/d	m3/h	m3/d	m3/h	m3/d	am3/h	am3/d	%	%
1	8.3	200	8.3	200.0	0.0	0.0	4.2	100	0	0
2	41.7	1000	41.7	1000.0	0.0	0.0	4.2	100	0	0
3	8.3	200	0.0	0.0	8.3	200.0	4.2	100	100	0
4	41.7	1000	0.0	0.0	41.7	1000.0	4.2	100	100	0
5	0.0	10	0.0	0.0	0.0	0.0	83.3	2000.0	0	100
6	0.0	10	0.0	0.0	0.0	0.0	125.0	3000.0	0	100
7	0.0	10	0.0	0.0	0.0	0.0	208.3	5000.0	0	100
8	0.0	10	0.0	0.0	0.0	0.0	333.3	8000.0	0	100
9	2.1	50	2.1	50.0	0.0	0.0	67.4	1616.7	0	97
10	2.1	50	2.1	50.0	0.0	0.0	102.1	2450.0	0	98
11	2.1	50	2.1	50.0	0.0	0.0	206.3	4950.0	0	99
13	2.9	70	0.0	0.0	2.9	70.0	33.5	805.0	100	92
14	2.9	70	0.0	0.0	2.9	70.0	70.0	1680.0	100	96
15	2.9	70	0.0	0.0	2.9	70.0	142.9	3430.0	100	98
16	2.9	70	0.0	0.0	2.9	70.0	288.8	6930.0	100	99
17	5.0	120	3.0	72.0	2.0	48.0	20.0	480.0	40	80
18	5.0	120	3.0	72.0	2.0	48.0	33.5	803.1	40	87
19	5.0	120	3.0	72.0	2.0	48.0	66.4	1594.3	40	93
20	5.0	120	3.0	72.0	2.0	48.0	120.0	2880.0	40	96
21	5.0	120	3.0	72.0	2.0	48.0	245.0	5880.0	40	98
22	8.3	200	3.3	80.0	5.0	120.0	5.6	133.3	60	40
23	8.3	200	3.3	80.0	5.0	120.0	8.3	200.0	60	50
24	8.3	200	3.3	80.0	5.0	120.0	12.5	300.0	60	60
25	8.3	200	3.3	80.0	5.0	120.0	19.4	466.7	60	70
26	8.3	200	5.8	140.0	2.5	60.0	33.3	800.0	30	80
27	8.3	200	5.8	140.0	2.5	60.0	75.0	1800.0	30	90
28	8.3	200	5.8	140.0	2.5	60.0	158.3	3800.0	30	95
29	12.5	300	3.8	90.0	8.8	210.0	5.4	128.6	70	30
30	12.5	300	3.8	90.0	8.8	210.0	12.5	300.0	70	50
31	12.5	300	3.8	90.0	8.8	210.0	18.8	450.0	70	60
32	12.5	300	7.5	180.0	5.0	120.0	29.2	700.0	40	70
33	12.5	300	7.5	180.0	5.0	120.0	50.0	1200.0	40	80
34	12.5	300	7.5	180.0	5.0	120.0	112.5	2700.0	40	90
35	20.8	500	16.7	400.0	4.2	100.0	5.2	125.0	20	20
36	20.8	500	16.7	400.0	4.2	100.0	8.9	214.3	20	30
37	20.8	500	16.7	400.0	4.2	100.0	20.8	500.0	20	50
38	20.8	500	10.4	250.0	10.4	250.0	48.6	1166.7	50	70
39	20.8	500	10.4	250.0	10.4	250.0	83.3	2000.0	50	80
40	29.2	700	5.8	140.0	23.3	560.0	7.3	175.0	80	20
41	29.2	700	5.8	140.0	23.3	560.0	12.5	300.0	80	30
42	29.2	700	5.8	140.0	23.3	560.0	29.2	700.0	80	50
43	29.2	700	5.8	140.0	23.3	560.0	62.0	1487.5	80	68
44	37.5	900	3.8	90.0	33.8	810.0	6.6	158.8	90	15
45	37.5	900	3.8	90.0	33.8	810.0	16.1	385.7	90	30
46	37.5	900	3.8	90.0	33.8	810.0	37.5	900.0	90	50
47	37.5	900	30.0	720.0	7.5	180.0	9.4	225.0	20	20
48	37.5	900	30.0	720.0	7.5	180.0	25.0	600.0	20	40

Once the FR MPFM characterisation was completed and functionality approved by Haimo personnel, a 'blind' test was carried out over a range of multiphase flow conditions supplied by Haimo shown in Table 2. The protocol for this type of blind test is outlined in Section 5.2.

TABLE 2

MPFM EVALUATION MATRIX

3inch SP+Full Range MPFM										
	Liquid		Oil		Water		Gas		BS&W	GVF
No.	m3/h	m3/d	m3/h	m3/d	m3/h	m3/d	am3/h	am3/d	%	%
1	16.7	400	16.7	400.0	0.0	0.0	0.0	0	0	0
2	41.7	1000	41.7	1000.0	0.0	0.0	0.0	0	0	0
3	8.3	200	0.0	0.0	8.3	200.0	0.0	0	100	0
4	41.7	1000	0.0	0.0	41.7	1000.0	0.0	0	100	0
5	0.0	10	0.0	0.0	0.0	0.0	125.0	3000.0	0	100
6	0.0	10	0.0	0.0	0.0	0.0	208.3	5000.0	0	100
7	0.0	10	0.0	0.0	0.0	0.0	333.3	8000.0	0	100
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15	5.0	120	3.0	72.0	2.0	48.0	20.0	480.0	40	80
16	5.0	120	3.0	72.0	2.0	48.0	33.5	803.1	40	87
17	5.0	120	3.0	72.0	2.0	48.0	66.4	1594.3	40	93
18	5.0	120	3.0	72.0	2.0	48.0	120.0	2880.0	40	96
19	5.0	120	3.0	72.0	2.0	48.0	245.0	5880.0	40	98
20	8.3	200	3.3	80.0	5.0	120.0	5.6	133.3	60	40
21	8.3	200	3.3	80.0	5.0	120.0	8.3	200.0	60	50
22	8.3	200	3.3	80.0	5.0	120.0	12.5	300.0	60	60
23	8.3	200	3.3	80.0	5.0	120.0	19.4	466.7	60	70
24	8.3	200	5.8	140.0	2.5	60.0	33.3	800.0	30	80
25	8.3	200	5.8	140.0	2.5	60.0	75.0	1800.0	30	90
26	8.3	200	5.8	140.0	2.5	60.0	158.3	3800.0	30	95
27	12.5	300	3.8	90.0	8.8	210.0	5.4	128.6	70	30
28	12.5	300	3.8	90.0	8.8	210.0	12.5	300.0	70	50
29	12.5	300	3.8	90.0	8.8	210.0	18.8	450.0	70	60
30	12.5	300	7.5	180.0	5.0	120.0	29.2	700.0	40	70
31	12.5	300	7.5	180.0	5.0	120.0	50.0	1200.0	40	80
32	12.5	300	7.5	180.0	5.0	120.0	112.5	2700.0	40	90
33	20.8	500	16.7	400.0	4.2	100.0	5.2	125.0	20	20
34	20.8	500	16.7	400.0	4.2	100.0	8.9	214.3	20	30
35	20.8	500	16.7	400.0	4.2	100.0	20.8	500.0	20	50
36	20.8	500	10.4	250.0	10.4	250.0	48.6	1166.7	50	70
37	20.8	500	10.4	250.0	10.4	250.0	83.3	2000.0	50	80
38	29.2	700	5.8	140.0	23.3	560.0	7.3	175.0	80	20
39	29.2	700	5.8	140.0	23.3	560.0	12.5	300.0	80	30
40	29.2	700	5.8	140.0	23.3	560.0	29.2	700.0	80	50
41	29.2	700	5.8	140.0	23.3	560.0	62.0	1487.5	80	68
42	37.5	900	3.8	90.0	33.8	810.0	6.6	158.8	90	15
43	37.5	900	3.8	90.0	33.8	810.0	16.1	385.7	90	30
44	37.5	900	3.8	90.0	33.8	810.0	37.5	900.0	90	50
45	37.5	900	30.0	720.0	7.5	180.0	9.4	225.0	20	20
46	37.5	900	30.0	720.0	7.5	180.0	25.0	600.0	20	40

5.2 Test Procedure

Test points from the ‘blind’ FAT test matrix were carried out by the NEL Facility operator in the order which best suits the facility operational efficiency. Each test point was logged once the facility operator was satisfied that the required flow condition had been achieved and was stable, and the Haimo representative was satisfied that the meter response was also stable. Data logging was carried out for a period of 5 minutes per flow condition in single-phase liquid flow, 10 minutes for single-phase gas flow and 15 minutes up to 95% GVF in three-phase flow. Most test conditions above 95% GVF were logged for 20 minutes unless the flow regime was particularly stable, when a 15 minute logging interval was used.

The NEL multiphase facility control computer and the Haimo FR MPFM data acquisition system clocks were synchronised prior to testing. The FR MPFM data logging was continuous, so data were analysed by comparing the facility reference data with the average of the FR MPFM data over the relevant test period. Reference data was given to Haimo once the FR MPFM log files were received and checked by the NEL multiphase facility operator.

6 TEST RESULTS

Test points were not necessarily carried out in the order given in Table 2, but were instead carried out in the most suitable order for facility operational efficiency. Test point numbers 28, 32 and 40 were repeated at the request of the Haimo personnel present during the test bringing the total number of test points recorded to 49. The results of all tests have been reported.

The manufacturer's published uncertainty for the Haimo Full Range MPFM multiphase flow meter is shown in Table 3. Table 4 shows the FR MPFM and NEL multiphase flow facility combined uncertainty against which the FR MPFM performance has been evaluated.

TABLE 3

PUBLISHED UNCERTAINTY FOR A HAIMO FULL RANGE MPFM

Haimo Full Range MPFM Uncertainty		
Full Range MPFM 0-100% GVF	**RMSE**	**90% CL**
Liquid Error (%,Rel)	4	6
Gas flow Error (%, Rel)	5	7
WLR Error (%, Abs)	1.5	2

TABLE 4

HAIMO FULL RANGE MPFM AND NEL FLOW LOOP COMBINED UNCERTAINTY

Haimo Full Range MPFM And NEL Combined Uncertainty	
Full Range MPFM 0-100% GVF	**90% CL**
Liquid Error (%,Rel)	6.06
Gas flow Error (%, Rel)	7.11
WLR Error (%, Abs)	2.17

The numerical results from the test programme are given in Appendix A, Table 6 at the end of this report.

Table 5, below, shows the root-mean-square errors (RMSE) and standard deviation for all the test results.

The standard deviation is defined as:

$$\sqrt{\frac{\sum (x-\bar{x})^2}{(n-1)}}$$

TABLE 5

HAIMO FULL RANGE MPFM – RMSE AND STANDARD DEVIATION

Haimo Full Range MPFM Test Results			
Full Range MPFM 0-100% GVF	**RMSE**	**Standard Deviation**	**(StDev)*1.64**
Liquid flow rate (%,Rel)	3.44	3.43	5.63
Gas flow rate (%, Rel)	4.44	4.46	7.31
WLR (%, Abs)	1.08	1.08	1.77

It should be noted that the standard deviation and RMSE were not used to evaluate the meter performance in this report as the reference and Haimo meter measurements each have an associated uncertainty. Hence, the values from Table 4 (combined uncertainties) are used to evaluate the meter performance.

Figure 4, below, shows how the actual test conditions achieved during the FAT test compared with the requested set points shown in Table 2. It can be seen from Figure 4 that the actual flow conditions set closely match the flow conditions requested by Haimo.

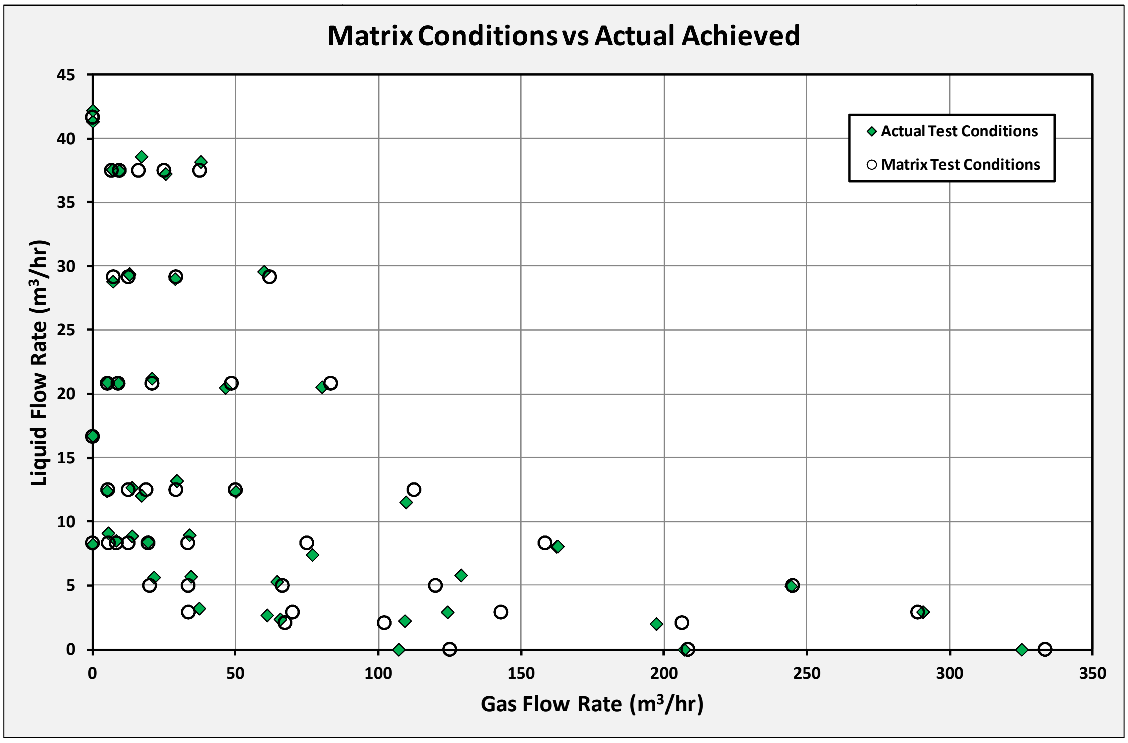

Figure 4 FAT Matrix Versus Actual Conditions Achieved

6.1 Liquid Flow Performance

Figure 5, below, shows the liquid flow rate plotted against the reference gas volume fraction for the Haimo Full Range MPFM. The data are compared with a combined error band, consisting of the FR MPFM uncertainty shown in Table 3 and the reference flow rate uncertainties detailed in Section 4.2. The individual uncertainties have been combined by converting to standard uncertainties, combining by the root sum squared method then multiplying by a coverage factor of k=1.64. Thus the combined uncertainty is quoted at a 90% confidence level.

The combined uncertainties for liquid flow rate, gas flow rate and water cut are shown in Table 4.

It can be seen from Figure 5 that 44 of 49 test points lie within specification on liquid flow. The errors in liquid flow appear to increase with increasing GVF. This is to be expected since the liquid flow rate is very low at high GVF.

The largest error in the measured liquid flow rate was 9.48% at a reference GVF of 99%.

The liquid flow errors show a total spread of 17.58% with a mean offset of 0.53% and a standard deviation of 3.43%.

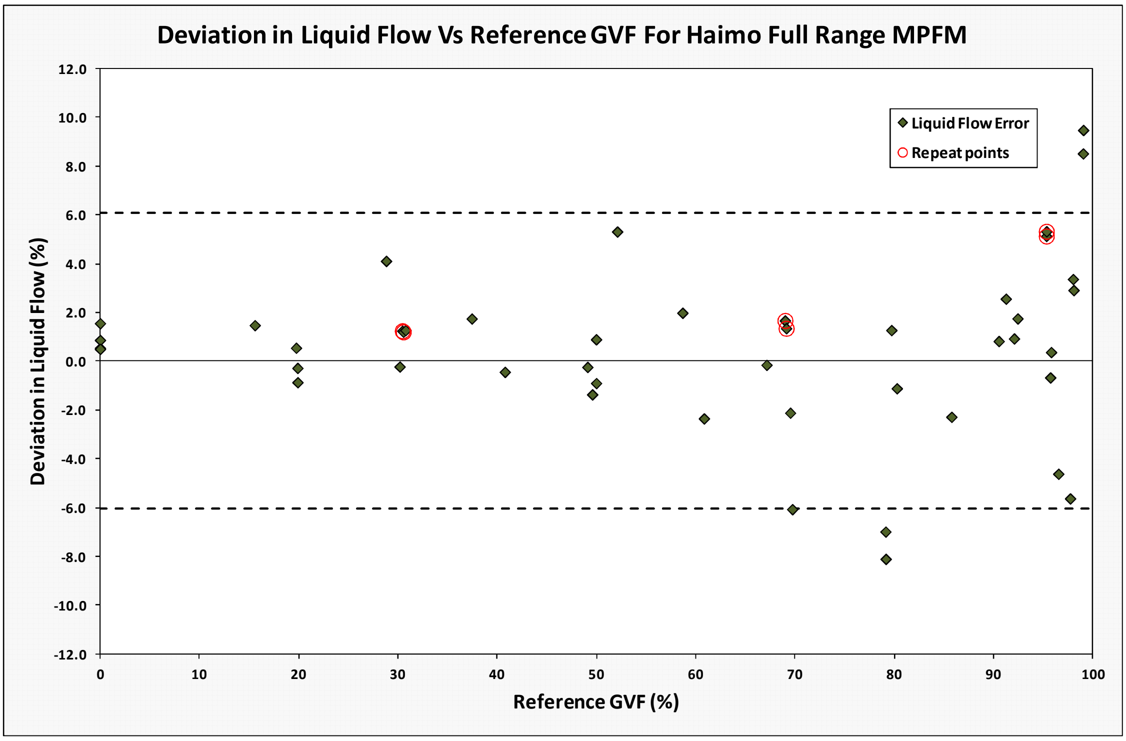

Figure 5 Error in Meter-Indicated Liquid Flow Rate Versus Reference GVF for Haimo Full Range MPFM

6.2 Gas Flow Performance

Figure 6, below, illustrates the FR MPFM meter gas flow performance. The uncertainty bands displayed are the combined uncertainties as described in section 6.1 and shown in Table 4. Reference gas flow rates have been converted to pressure and temperature conditions as reported by the FR MPFM to allow direct comparison. Figure 6 shows that 47 of 49 test points are within the combined uncertainty.

The meter's gas flow performance displayed a maximum error of -13.49% at a reference GVF of 99%.

The gas flow errors show a total spread of 23.3% with a mean offset of -0.45% and a standard deviation of 4.46%.

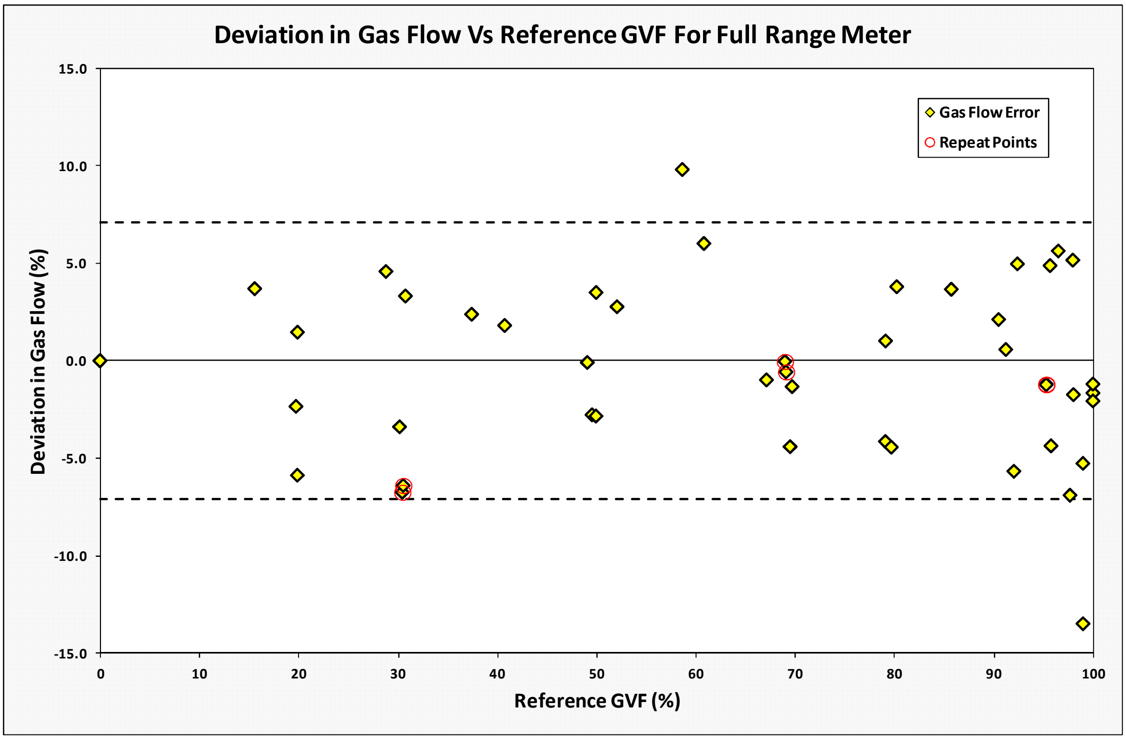

Figure 6 Error in Meter-Indicated Gas Flow Rate Versus Reference GVF for Haimo Full Range MPFM

6.3 Water Cut Performance

The water cut performance of the Haimo FR MPFM is shown in Figure 7 with respect to reference GVF where 47 of 49 test points were within the water-cut combined uncertainty shown in Table 4. Figure 7 shows that the largest errors in water-cut were measured at a GVF of greater than 98%. Measurement performance deteriorates slightly at GVFs of 95% and above, though 80% of these measurements remain within uncertainty.

Figure 8 shows the same data plotted against reference water cut. It can be seen from Figure 8 that the largest error in water cut was seen at a reference water cut of 45%. The only other water-cut measurement outside the combined uncertainty band was at a reference water cut of 100%.

The maximum deviation from the reference water cut was 5% absolute.

The water cut errors show a total spread of 7.62% with a mean offset of 0.16% and a standard deviation of 1.08%.

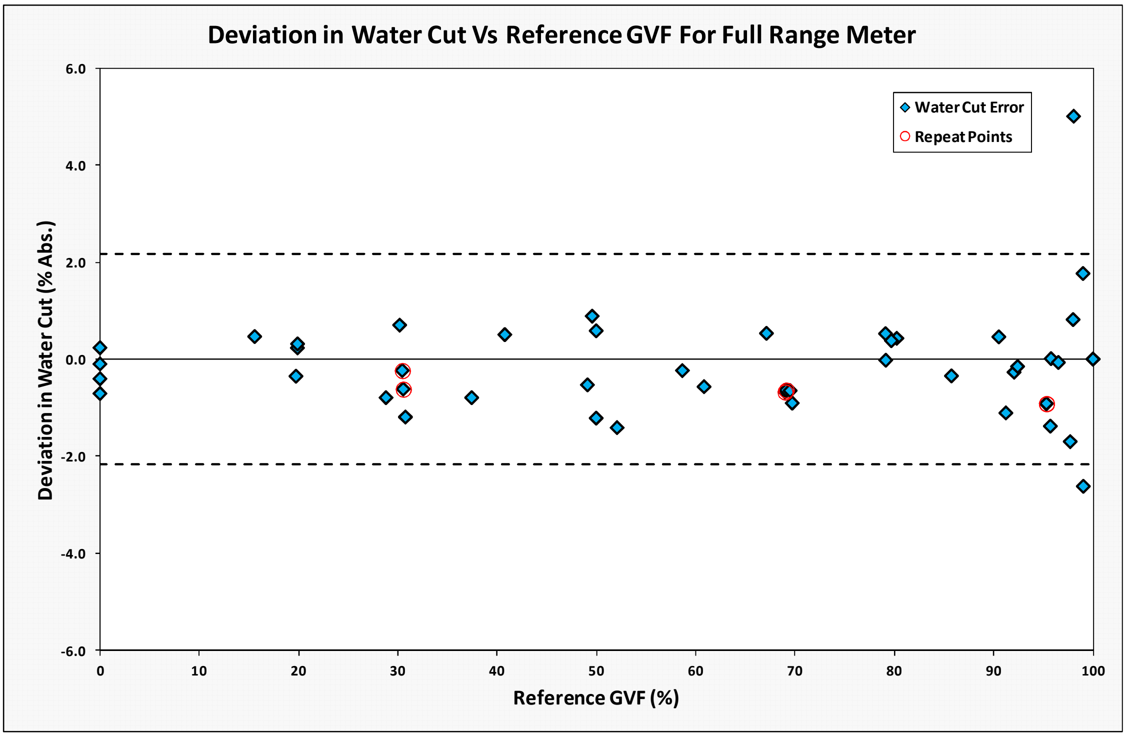

Figure 7 Error in Meter-Indicated Water Cut Versus Reference GVF for Haimo Full Range MPFM

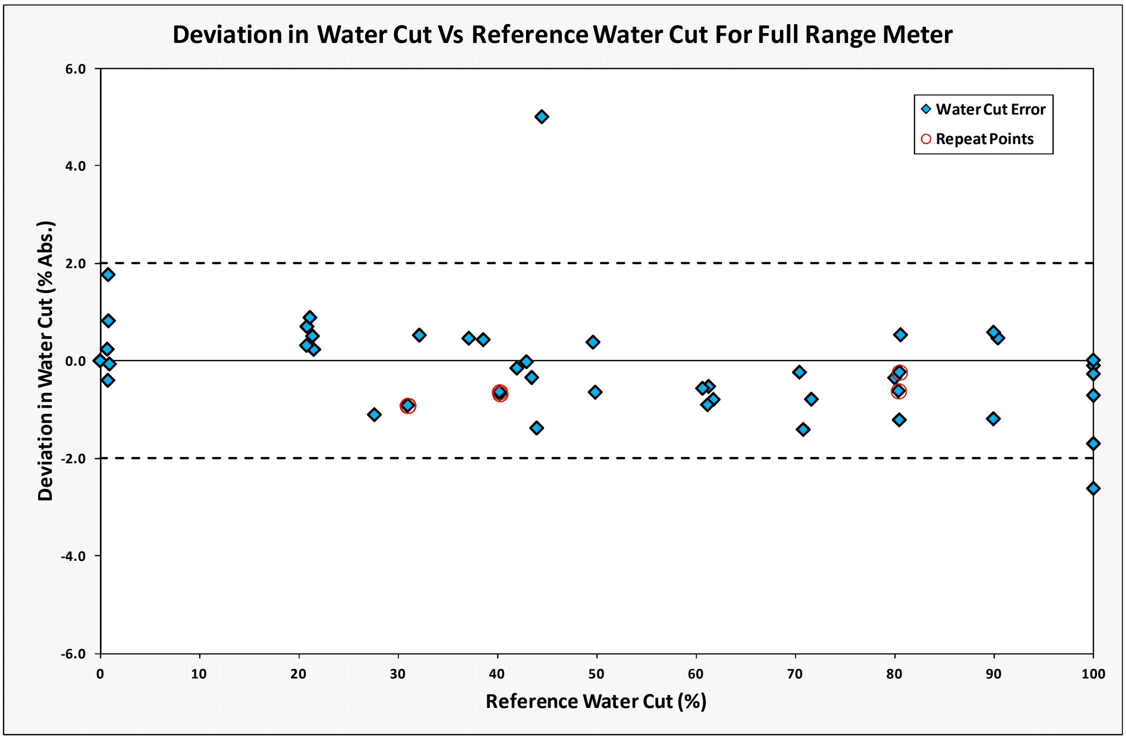

Figure 8 Error in Meter-Indicated Water Cut Versus Reference Water Cut for Haimo Full Range MPFM

7 CONCLUSIONS

During the test programme a total of 46 test conditions were logged across an agreed matrix of multiphase mixtures on a Haimo Full Range Multiphase Flow Meter. 3 of the test points were repeated bringing the total number of tests reported to 49. The test programme results have been analysed and presented numerically and graphically showing the performance of the test meter with respect to the specification published by Haimo shown in Table 3 combined with the NEL multiphase flow facility uncertainty (Table 4).

In a comparison against the manufacturer's performance specification, 138 of 147 of the meter's individual measurements of liquid flow rate, gas flow rate and water cut were within the combined meter and facility uncertainty specification as described in section 6 of this report.

More than 93.8% of all the Haimo Full Range Multiphase Flow Meter's individual measurements of liquid flow, gas flow and water cut, during this evaluation, were within the meter's current published uncertainty specification.

APPENDIX A

TABULATED RESULTS

TABLE 6

RESULTS SHOWING REFERENCE AND HAIMO FR MPFM FLOWRATES WITH ASSOCIATED DEVIATIONS

NEL Multiphase Facility Reference Measurements													Corrected To FR MPFM P & T		HAIMO FR MPFM Measurement						Deviations		
Matrix Test Point	Collection Date & Time	Abs. Pres. U/S	Local Temp	Oil Density	Water Density	Gas Density	Oil Vol. Flow	Water Vol. Flow	Liquid Vol. Flow	Gas Vol. Flow	Gas Vol. Fraction	Water Vol.Cut	Gas Vol. Flow	Gas Vol. Fraction	Liquid Flow	Gas flow	GVF	WLR	T	P	Liquid Flow	Gas Flow	Water Cut
		Bar	°C	kg/m³	kg/m³	kg/m³	litre/s	litre/s	litre/s	litre/s	%	%	litre/s	%	am³/d	am³/d	%	%	°C	kPa	%	%	% Abs.
5	15/05/2014 09:43	11.052	17.02	830.89	1047.23	12.87	0.000	0.000	0.000	29.729	100.00	0.00	29.759	100.00	0.06	2528.47	100.00	0.00	17.00	1104.00	N/A	-1.66	0.00
6	15/05/2014 10:07	8.591	13.84	832.98	1047.94	10.11	0.000	0.000	0.000	57.482	100.00	0.00	57.881	100.00	0.12	4897.56	100.00	0.00	14.92	856.44	N/A	-2.07	0.00
7	15/05/2014 10:26	4.985	10.65	835.08	1048.56	5.93	0.000	0.000	0.000	90.281	100.00	0.00	91.864	100.00	2.15	7841.55	99.97	0.00	12.17	492.50	N/A	-1.20	0.00
3	15/05/2014 10:54	3.702	19.61	829.20	1046.58	4.26	0.000	2.289	2.289	0.000	0.00	100.00	0.000	0.00	200.84	0.34	0.17	99.90	19.10	356.64	1.56	N/A	-0.10
4	15/05/2014 11:05	3.434	19.41	829.33	1046.63	3.96	0.000	11.484	11.484	0.000	0.00	100.00	0.000	0.00	997.68	4.12	0.41	99.29	19.12	325.21	0.55	N/A	-0.71
11	15/05/2014 11:27	9.861	21.49	827.97	1046.07	11.30	0.000	0.896	0.896	10.336	92.02	100.00	10.368	92.05	78.13	844.97	91.54	99.73	20.69	980.37	0.93	-5.68	-0.27
12	15/05/2014 12:02	11.659	20.74	828.46	1046.28	13.40	0.000	0.748	0.748	16.938	95.77	99.99	16.957	95.78	64.87	1401.14	95.57	100.00	20.51	1163.69	0.37	-4.37	0.01
13	15/05/2014 12:34	10.680	20.77	828.44	1046.27	12.27	0.000	0.815	0.815	34.478	97.69	100.00	34.583	97.70	66.43	2781.62	97.67	98.30	20.54	1063.88	-5.62	-6.91	-1.70
14	15/05/2014 13:05	6.090	18.81	829.72	1046.78	7.04	0.000	0.820	0.820	80.683	98.99	100.00	82.236	99.01	77.56	6146.48	98.75	97.38	19.14	598.16	9.48	-13.49	-2.62
15	15/05/2014 13:47	10.857	20.66	828.51	1046.30	12.48	0.897	0.675	1.572	5.946	79.09	42.93	5.958	79.12	124.83	519.98	80.64	42.91	20.06	1081.32	-8.10	1.01	-0.02
16	15/05/2014 14:21	10.747	21.55	827.93	1046.06	12.31	0.898	0.690	1.589	9.536	85.72	43.46	9.554	85.74	134.14	855.71	86.45	43.11	21.15	1071.19	-2.28	3.66	-0.35
17	15/05/2014 14:54	11.079	21.60	827.90	1046.04	12.69	0.857	0.619	1.476	17.902	92.38	41.95	17.944	92.40	129.76	1627.33	92.62	41.80	21.21	1103.82	1.75	4.96	-0.15
18	15/05/2014 15:26	10.581	21.38	828.04	1046.10	12.13	0.907	0.711	1.618	35.785	95.68	43.95	35.945	95.69	138.83	3257.19	95.91	42.57	21.18	1052.67	-0.67	4.88	-1.38
19	15/05/2014 16:01	6.388	19.83	829.06	1046.52	7.36	0.766	0.614	1.380	67.863	98.01	44.48	69.097	98.04	122.74	5865.82	97.95	49.48	19.91	627.54	2.91	-1.74	5.00
20	15/05/2014 16:38	10.680	20.09	828.89	1046.45	12.30	0.970	1.564	2.533	1.505	37.27	61.73	1.515	37.43	222.71	134.04	37.57	60.93	20.05	1060.90	1.75	2.38	-0.80
21	15/05/2014 17:02	10.906	20.50	828.62	1046.34	12.54	0.919	1.454	2.373	2.275	48.95	61.27	2.288	49.08	204.55	197.48	49.12	60.74	20.36	1084.16	-0.24	-0.09	-0.53
22	15/05/2014 17:26	10.803	20.59	828.56	1046.32	12.42	0.972	1.498	2.470	3.815	60.70	60.66	3.835	60.82	208.39	351.21	62.76	60.09	20.48	1074.49	-2.35	6.01	-0.57
23	15/05/2014 17:51	10.939	20.64	828.52	1046.30	12.57	0.910	1.432	2.341	5.358	69.59	61.15	5.388	69.71	190.02	459.31	70.74	60.24	20.57	1087.66	-6.06	-1.33	-0.91
24	15/05/2014 18:16	10.666	20.56	828.58	1046.33	12.26	1.692	0.801	2.493	9.398	79.03	32.15	9.436	79.10	200.37	781.47	79.59	32.67	20.43	1061.75	-6.98	-4.15	0.52
25	15/05/2014 18:38	11.104	20.55	828.58	1046.33	12.77	1.493	0.570	2.062	21.342	91.19	27.62	21.436	91.22	182.76	1862.59	91.06	26.51	20.47	1105.25	2.56	0.57	-1.11
26	15/05/2014 19:12	10.249	20.15	828.84	1046.44	11.80	1.548	0.693	2.241	45.079	95.26	30.92	45.401	95.30	203.54	3875.52	95.01	30.00	20.03	1017.18	5.13	-1.20	-0.92
26R	15/05/2014 19:29	10.239	20.13	828.86	1046.44	11.79	1.550	0.695	2.245	45.201	95.27	30.97	45.501	95.30	204.30	3882.86	95.00	30.06	19.93	1016.42	5.33	-1.23	-0.91
27	15/05/2014 19:58	11.228	20.07	828.89	1046.46	12.93	0.980	2.472	3.452	1.389	28.70	71.61	1.397	28.81	310.51	126.20	28.90	70.82	19.93	1116.37	4.11	4.57	-0.79
28	15/05/2014 20:21	10.921	20.21	828.81	1046.42	12.57	1.030	2.494	3.524	3.811	51.96	70.78	3.829	52.08	320.65	340.00	51.46	69.37	20.13	1086.76	5.31	2.76	-1.41
29	15/05/2014 20:43	11.181	20.42	828.67	1046.37	12.86	0.991	2.358	3.349	4.737	58.58	70.42	4.750	58.65	295.12	450.63	60.43	70.18	20.20	1114.32	1.99	9.80	-0.24
30	15/05/2014 21:06	10.841	20.85	828.39	1046.25	12.45	2.195	1.478	3.672	8.136	68.90	40.24	8.165	68.98	322.58	705.18	68.61	39.56	20.52	1078.97	1.67	-0.04	-0.68
30R	15/05/2014 21:23	10.832	20.87	828.38	1046.24	12.44	2.195	1.475	3.671	8.182	69.03	40.20	8.207	69.10	321.42	704.96	68.68	39.56	20.51	1078.68	1.35	-0.58	-0.64
31	15/05/2014 21:47	11.065	20.77	828.44	1046.27	12.71	2.109	1.325	3.434	13.909	80.20	38.57	13.944	80.24	293.40	1250.45	81.00	39.00	20.38	1102.25	-1.11	3.79	0.43
32	15/05/2014 22:14	11.226	20.65	828.52	1046.30	12.90	2.015	1.190	3.205	30.446	90.48	37.13	30.562	90.51	279.22	2696.28	90.62	37.59	20.27	1116.89	0.83	2.11	0.46
33	16/05/2014 09:10	10.174	20.42	828.67	1046.36	11.70	4.561	1.250	5.811	1.432	19.77	21.51	1.442	19.88	500.70	117.29	18.98	21.74	20.15	1009.12	-0.28	-5.88	0.23
34	16/05/2014 09:36	10.569	20.36	828.71	1046.38	12.16	4.589	1.207	5.796	2.490	30.05	20.83	2.504	30.17	499.70	209.04	29.49	21.53	20.16	1049.96	-0.22	-3.39	0.70
35	16/05/2014 10:00	10.402	20.44	828.65	1046.36	11.96	4.650	1.246	5.896	5.761	49.42	21.13	5.795	49.57	502.49	486.72	49.20	22.01	20.24	1033.43	-1.36	-2.78	0.88
36	16/05/2014 10:26	10.811	20.11	828.87	1046.45	12.45	2.857	2.839	5.696	12.894	69.36	49.85	12.981	69.50	481.75	1072.05	69.00	49.20	20.05	1073.59	-2.11	-4.41	-0.65
37	16/05/2014 10:51	10.739	20.09	828.88	1046.45	12.37	2.877	2.835	5.712	22.274	79.59	49.63	22.418	79.69	499.78	1850.99	78.74	50.01	20.00	1066.67	1.28	-4.43	0.38
38	16/05/2014 11:18	10.685	19.02	829.59	1046.73	12.35	1.602	6.404	8.006	1.953	19.61	79.99	1.969	19.74	695.51	166.12	19.28	79.64	19.61	1062.02	0.55	-2.34	-0.35
39	16/05/2014 11:43	10.352	19.13	829.51	1046.70	11.96	1.598	6.576	8.174	3.553	30.30	80.45	3.577	30.44	715.02	288.18	28.73	80.22	19.16	1028.32	1.25	-6.75	-0.23
39R	16/05/2014 11:59	10.344	19.18	829.48	1046.69	11.95	1.602	6.554	8.157	3.560	30.39	80.36	3.585	30.54	713.22	289.95	28.90	79.74	19.19	1027.20	1.21	-6.40	-0.62
40	16/05/2014 12:25	10.391	19.23	829.45	1046.68	12.00	1.575	6.487	8.062	7.998	49.80	80.46	8.048	49.96	702.79	675.63	49.01	79.25	19.26	1032.70	0.90	-2.84	-1.21
41	16/05/2014 12:51	10.660	19.31	829.39	1046.66	12.31	1.596	6.623	8.220	16.636	66.93	80.58	16.781	67.12	709.15	1435.53	66.93	81.11	19.46	1057.27	-0.15	-0.99	0.53
42	16/05/2014 13:17	10.536	19.92	829.00	1046.50	12.14	1.005	9.435	10.439	1.911	15.47	90.38	1.926	15.58	915.28	172.58	15.86	90.84	19.96	1045.30	1.48	3.69	0.46
43	16/05/2014 13:45	10.715	20.77	828.44	1046.27	12.31	1.081	9.643	10.723	4.727	30.59	89.92	4.764	30.76	938.29	425.25	31.19	88.73	20.64	1062.61	1.27	3.31	-1.19
44	16/05/2014 14:10	10.392	21.44	828.00	1046.09	11.91	1.067	9.542	10.608	10.498	49.74	89.95	10.593	49.97	908.35	947.30	51.05	90.53	21.18	1028.92	-0.90	3.50	0.58
45	16/05/2014 14:39	10.534	20.71	828.48	1046.29	12.10	8.249	2.166	10.415	2.560	19.73	20.80	2.586	19.89	892.10	226.67	20.26	21.11	21.68	1046.44	-0.86	1.46	0.31
46	16/05/2014 15:02	10.447	21.41	828.02	1046.10	11.97	8.136	2.213	10.349	7.069	40.58	21.38	7.122	40.76	890.25	626.44	41.30	21.89	21.36	1036.72	-0.44	1.80	0.51
8	16/05/2014 15:33	10.563	21.96	827.66	1045.94	12.09	0.653	0.006	0.660	18.219	96.51	0.95	18.241	96.51	54.36	1664.63	96.84	0.88	21.69	1054.14	-4.61	5.62	-0.07
9	16/05/2014 16:07	10.732	22.56	827.27	1045.77	12.25	0.620	0.005	0.625	30.335	97.98	0.85	30.380	97.98	55.84	2760.08	98.02	1.67	22.19	1070.23	3.37	5.15	0.82
10	16/05/2014 16:31	8.046	21.71	827.83	1046.01	9.21	0.557	0.005	0.562	54.775	98.98	0.81	55.119	98.99	52.66	4511.39	98.85	2.57	21.54	799.14	8.51	-5.27	1.76
1	16/05/2014 17:00	4.461	18.82	829.72	1046.78	5.15	4.614	0.034	4.648	0.000	0.00	0.72	0.000	0.00	405.06	0.00	0.00	0.96	21.50	434.31	0.87	N/A	0.24
2	16/05/2014 17:12	4.706	19.17	829.49	1046.69	5.43	11.633	0.093	11.726	0.000	0.00	0.79	0.000	0.00	1018.27	0.29	0.03	0.39	21.40	457.85	0.51	N/A	-0.40