i-Vigilant Technologies Limited

iVJob22008-SVR-001 (Flow Test Report)

Flow Test Report

Customer:	Cadent
Customer Reference	3200905035
i-Vigilant Reference:	iVJob22008-SVR-001-F01
iVJob22008-SVR-001 (Flow Test Report) Flow Test Report	
Date of Issue:	23rd May 2022
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DOCUMENT REVISONS

Rev	Date	Comment	Prepared By
D01	23/05/22	Initial Draft.	Paul Daniel
F01	24/05/22	Data internally reviewed and final report issued	Paul Daniel

HOLDS

Hold	Description
	None

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1 Executive Summary

Cadent identified a measurement error at the Alrewas site caused by the incorrect orientation of the orifice plates. Following an initial investigation by an Independent Technical Expert (ITE), i-Vigilant has been appointed as the second ITE to undertake a second separate investigation.

To establish the measurement error caused by the reverse installation of the orifice plates a clamp-on ultrasonic meter was installed upstream and in series with the orifice and both orifice plates that had been used in the reverse orientation have been flow tested in both the forward and reverse orientation. The USM can then be used to establish the measurement error when the plates are installed in reverse orientation.

This report details the results of the flow tests which were performed over a four day period between the 16th–20th May 2022.

The tests carried out over 4 days are,

- Day 1: Clamp-on USM installation and flow testing of plate 1 in the forward direction.
- Day 2: Installation and flow testing of plate 1 in the reverse orientation and installation of plate 2 in the forward orientation.
- Day 3: Flow testing of plate 2 in the forward orientation.
- Day 4: Installation and flow testing of plate 2 in the reverse orientation.

A summary of the results are presented in Table 1. The test carried out on plate 295/5 in the forward orientation was used to establish a Meter Factor for the tests carried out in the reverse orientation. The second plate was tested in the forward orientation to confirm the Meter Factor and demonstrate the reproducibility of the USM.

Table 1: Flow Test Result Summary

Flow Test	Average Flow (sm3/hr)	MF / Error (%)	CFD Fluent (% Error)	CFD CFX (% Error)
1 – 295/5 Forward	153,153	0.9719 / -2.811%	-	-
2 – 295/5 Reverse	168,355	-5.814%	-4.92%	-5.58%
3 – ARLE5036 Forward	157,651	-0.025%	-	-
4 – ARLE5036 Reverse	165,326	-4.324%	-3.62%	-4.07%

The orifice 295/5 read 2.811% lower than the clamp-on USM during the first test. This was used to determine a meter factor of 0.9719 which was subsequently applied to the 3 remaining tests to establish the presented error in Table 1.

Based on the flow testing performed, plate 295/5 under measured in the reverse orientation by 5.814%. This compares to a 5.58% under measurement predicted by the CFX CFD, a difference of only 0.23%.

Based on the flow testing performed, plate ARLE5036 under measured in the reverse orientation by 4.324%. This compares to a 4.07% under measurement predicted by the CFX CFD, a difference of only 0.254%.

The difference between the plate ARLE5036 and the USM with a meter factor applied to it was only -0.025%. The demonstrated excellent reproducibility for the USM and the tests.

The sample interval for the orifice data was determined by the DANINT system and was 7-8 minutes. The difference between the mean taken from the instantaneous 7 minutely samples and the average flow rate determined from the totaliser 'snapped' at the same interval was between 0.2-0.3%. This may be considered as the uncertainty of the average from the data recorded by the DANINT system. Bearing in mind the slow sample rate and the fact that flow had to be diverted to the Alrewas site in order to perform the tests (demand is such that flow is not normally required at this site during this time of the year) the results represent a very successful series of flow tests.

The flow test results agreed very well with the CFD analysis using the CFX solver.

2 Introduction

Following the installation of 2 orifice plates in the reverse orientation i-Vigilant have been requested to establish the measurement error and to provide a Measurement Error Report.

The investigation has been undertaken in two parts:

- Part 1: CFD

  The Measurement Error has been determined using Computational Fluid Dynamics (CFD). The CFD has been undertaken using two types of simulation models, CFX and Fluent. Both orifice plates have been simulated at 3 flow rates in the forward and reverse orientations. The forward orientation simulation has been compared with ISO 5167.

- Part 2: Flow Testing

  Flow testing has also been carried out. The site testing used a clamp-on Ultrasonic Flow Meter (USM) installed upstream and in series with the orifice plate. Tests were done with the orifice plate in the correct orientation to establish a reference for the USM and with each plate installed in the reverse orientation.

The results of the CFD analysis have been presented in a separate report. This report provides details of the flow testing performed from 16th May through to the 20th May 2022.

3 Flow Testing

3.1 Scope of Tests

A clamp-on ultrasonic flowmeter (USM) was installed upstream of the orifice meter with the intent to use this as a reference to establish the measurement error when the orifice plate is installed in the reverse orientation. Due to the expected uncertainty of a clamp-on meter the USM was run in series with the orifice installed in the correct orientation. This run was used to calculate a Meter Factor (MF) for the USM which was used to determine the meter error for both orifice plates installed in the reverse orientation. As an additional baseline check and to confirm the reproducibility of the USM , the second orifice plate was also tested in the forward orientation.

The tests involved:

1. Install the clamp-on ultrasonic meter.
2. Confirm all data logging arrangements.
3. Flow Test 1 – The Baseline - Plate 295/5 correct orientation.
4. Flow Test 2 – Measurement Error Calculation – Plate 295/5 reverse orientation.
5. Flow Test 3 – Baseline check – Plate ARLE5036 in the forward orientation.
6. Flow Test 4 – Measurement Error Calculation – Plate ARELE5036 reverse orientation.
7. Re-installation of the original plate in the correct orientation.
8. Removal of the clamp-on USM.

Each of these items are described in more detail in the following sections.

3.2 Clamp-on Meter Installation

A Flexim portable flowmeter was used for the site testing. The meter was a Fluxus G608 as detailed in Table 2.

Table 2: USM Meter Details

Type	Details	Serial Number
Fluxus G608	G608-A22-3N-NN-2D-II-NN-NN	06080212
Fluxus GLK Transducer	GLK1NH3	99117

The transmitters were installed with a single diametric path arrangement as shown in Figure 1.

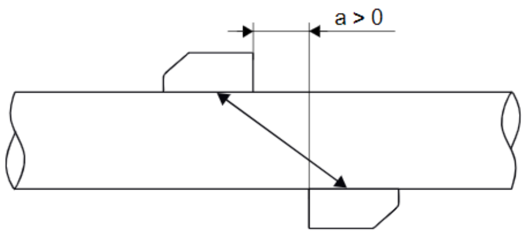

Figure 1: Transducer Orientation

The clamp-on USM was installed 2250mm or 5.2D upstream of the orifice meter (Figure 2).

The orifice has 49D of upstream straight length meaning there is approximately 44D of upstream stream length before the USM.

Figure 2: Clamp-on USM Installation

For the purpose of the testing it was assumed that the pressure, temperature and density at the USM is as measured by the orifice meter.

The USM was configured based on a measurement of the pipe wall thickness and the circumference of the pipe. The settings for the USM are provided in Table 3.

Table 3: USM Configuration Parameters

Parameter	Value	Units
Pipe Wall Thickness	12.3	mm
Outer Diameter	464.73	mm
Transducer Distance	22	mm
Nominal Transducer Frequency	500,000	Hz
Fluid	Natural Gas (90% Methane)	-
Pipe Material	Carbon Steel	-
Damping	10	seconds
Data Logger Averaging	Enabled	-
Data Logger Storage Rate	30	seconds

3.3 Data logging

3.3.1 Orifice System Data Logging

Data logging was performed for the orifice system using the on-site monitoring application DANINT. DANINT reads the flow measurement and gas quality information and stores it in comma separated text files. Two data files were utilised during the flow tests, the .V0x and .Z0x files. The storage rate is dictated by the GC cycle time and is 7 minutes for this site.

The .Z0x files were used to provide the standard volume totaliser, the instantaneous standard volume flow rate and the gas analysis information.

The V0x files were used to provide the differential pressure, pressure, temperature and the instantaneous standard volume flow rate.

An offline AGA 8 compressibility calculation was performed using the composition from the Z0x file and the pressure and temperature from the V0x file to establish the flowing and standard density. This was then used to,

- Perform an ISO 5167 calculation check to ensure the results were satisfactory.
- To convert actual volume flow rate at the USM to standard volume flow rate.

During the tests the totaliser and the instantaneous standard volume readings were manually recorded by viewing the V0x and Z0x files. This was to trend the readings and establish the stability as a check to ensure that sufficient data has been acquired.

For a statistically stationary process, the standard deviation of a set of n readings of a variable x, is given,

$$s(x) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

The standard deviation of the average is provided by,

$$s(\bar{x}) = \frac{s(x)}{\sqrt{n}}$$

The associated uncertainty of the average can be calculated using the student t statistic,

$$U(\bar{x}) = T(\%, n)s(\bar{x})$$

Where $T(\%, n)$ is the student t statistic for n degrees of freedom and a confidence interval given by $\%$. Typically 95% is used.

As more samples are taken the uncertainty of the average will reduce until it becomes the true value after an infinite number of evaluations.

The average flow rate was also calculated using the logged totaliser value,

$$SV_{av} = \frac{SV_{Tc} - SV_{To}}{T}$$

where,

SV_{av} is the average standard volumetric flow rate (sm^3/h) over the test period
SV_{Tc} is the closing totaliser value for the standard volume (sm^3) at the end of the test.
SV_{To} is the opening totaliser value for the standard volume (sm^3) at the start of the test.
T is the duration of the tests in hours.

As more samples are acquired the uncertainty of the average should decrease and the average from the instantaneous samples should tend towards the average flow rate established from the totaliser.

The tests were run for 4 hours with the stability monitored to try and ensure sufficient data was acquired to establish an accurate standard volume for comparison with the clamp-on USM meter.

3.3.2 USM Data logging

The Fluxux G608 transmitter supports local datalogging. The units of measurement, sample frequency, filter period, and storage interval are configured by the user when setting up data logging.

The data logger was configured to store averaged data every 30sec. The format of the data can be seen in Table 4.

The transmitter is battery operated and logs the data locally during the flow test. Following completion of each flow test the transmitter was connected to a laptop and the logged data downloaded and stored in CSV files.

Table 4: USM Data Format

Date	Flow velocity [m/s]	Volumetric flow rate [m³/h]	Sound speed [m/s]	Amplitude [%]	Amplification [dB]	Quality [%]	SCNR [dB]	SNR [dB]
5/17/2022 7:51:53 AM	0.05	29.03	391.63	30.00	104.30	100.00	41.00	27.00
5/17/2022 7:52:23 AM	0.06	31.22	391.64	30.00	104.30	99.00	39.00	27.00
5/17/2022 7:52:53 AM	0.05	29.58	391.66	30.00	104.30	99.00	39.00	27.00

3.4 Flow Test 1 - Plate 295/5 Correct Orientation

Flow test 1 was performed with the orifice plate 295/5 in the forward orientation.

3.4.1 Orifice Details

The orifice details entered in to the flow computer were taken from the latest calibration certificate (3802550005) and are presented in Table 5 below.

Table 5: Orifice Plate Metrology - 295/5 – Cert 3802550005

Calibration Certificate	Tescal: 3802550005	
Certificate Issue Date	4th April 2022	
Plate Identification	295/5	
Laboratory Temperature	20.1	DegC
Measured Bore Diameter	310.0055	mm
Nominal Pipe Diameter	432.2096	mm
Nominal Beta Ratio	0.7173	-
Plate Thickness ‘E’	9.28	mm
Thickness ‘e’	6.98	mm
Angle of Bevel	44	Degrees

(Note the CFD was based on an earlier calibration certificate).

3.4.2 Orifice Installation Details

Photographs of the orifice plates and direction of installation are provided in Figure 3 and Figure 4.

Figure 3 shows the front and rear of the orifice plate.

Figure 3: Orifice 295/5 Front and Rear

Figure 4 shows the installed orifice orientation. The orifice is installed in the correct orientation with the flow from left to right and the bevel on the downstream side.

Figure 4: Flow Test 1 - Installation of plate 1 (295/5)

3.4.3 Test Results

The flow test commenced at 08:00 with a throughput of approximately 160,000sm3/h and was completed by 12:00.

A plot of the flow rate over the period is presented in Figure 5. This plot shows a number of trends.

The blue trend is the flow rate established from the totaliser from the Z0x file as described in section 3.3.1. The grey trend is the average flow rate established by calculating the average flow rate for all instantaneous readings from the Z0x file from the start of the test to the time it is plotted.

The orange trend are the instantaneous readings taken from the Z0x file. The yellow trend is the Meter Factor corrected reading from the USM.

It can be seen from Figure 5 that it was not possible to maintain a constant flow rate, there was a significant dip in the flow rate at approximately 09:00 and the flow to the station ceased at just after 11:00.

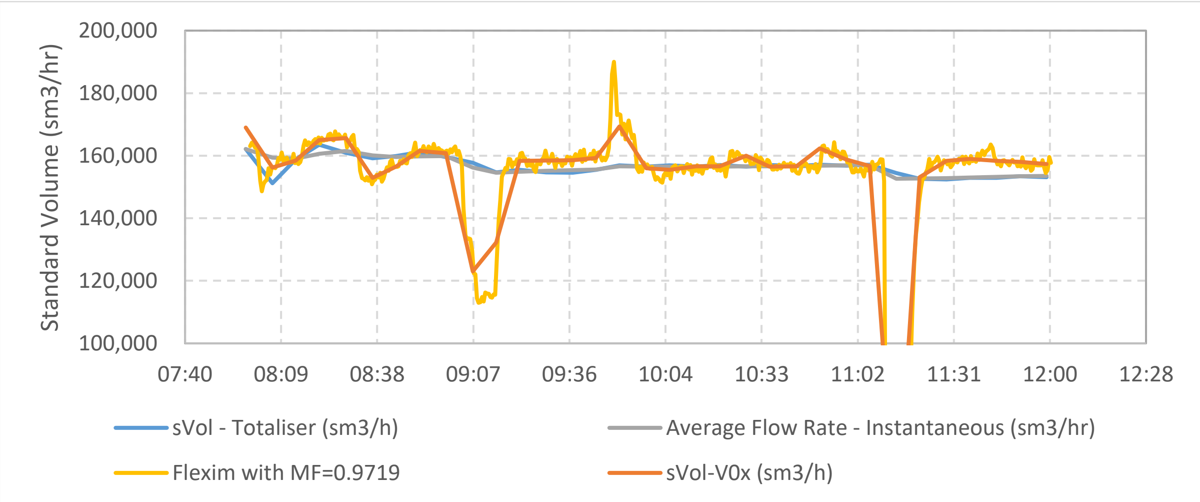

Figure 5: Flow Test 1 – USM and Orifice Flow Rates

The average flow rate has been calculated based on the totaliser and the instantaneous measured flow rates. The difference between these two figures is 0.23%. Based on the fluctuating flow rates and the sample frequency, this is considered to be a reasonable resolution for the average flow rate for the test.

Table 6: Flow Test 1 – Average Flow Rates and Meter Factor

Description	Value	Unit
Orifice: Average Flow Rate (sm3/hr) - Instantaneous	153,504	sm3/hr
Orifice: Average Flow Rate (sm3/hr) - Difference Total	153,153	sm3/hr
Orifice: Difference - Total-Instantaneous	-351.26	sm3/hr
Orifice: Difference - Total-Instantaneous	-0.23	%
USM: Average Flow Rate (sm3/hr)	157,583	sm3/hr
Difference between Orifice and USM	-2.811	%
USM Meter Factor	0.9719	

Table 6 shows the average flow rates for the orifice and USM over the test period. The difference between the USM and Orifice was 2.811%, which relates to a Meter Factor of 0.9719.

The orange trend in Figure 5 is the USM instantaneous reading after correction by the meter factor. It can be seen that the USM and Orifice are in close agreement after the application of the meter factor.

Figure 6 shows a trend of the instantaneous flow rate taken from the V0x file, the Z0x file and the flow rate calculated from the differential pressure from the V0x file. All data points are very close to one another providing confidence in the recorded data and the flow computer configuration and calculation.

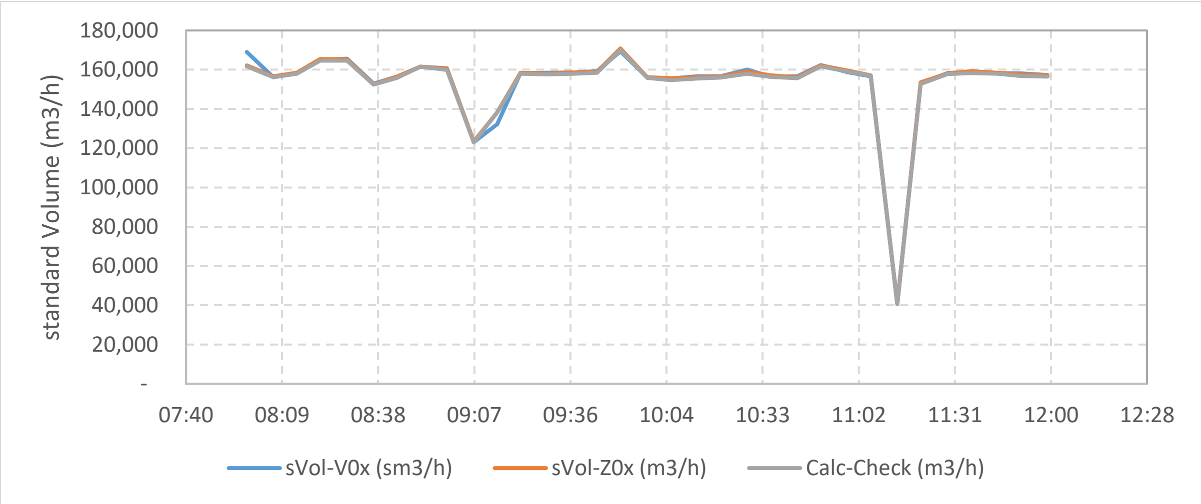

Figure 6: Flow Test 1 – Instantaneous Volume Flow Rates

Figure 7 shows the logged CV and Density from the Z0x file and the calculated values using ISO6976 and AGA8 calculations within excel based on the composition returned in the Z0x file. All values are coincident providing confidence in the logged data and the flow computer configuration.

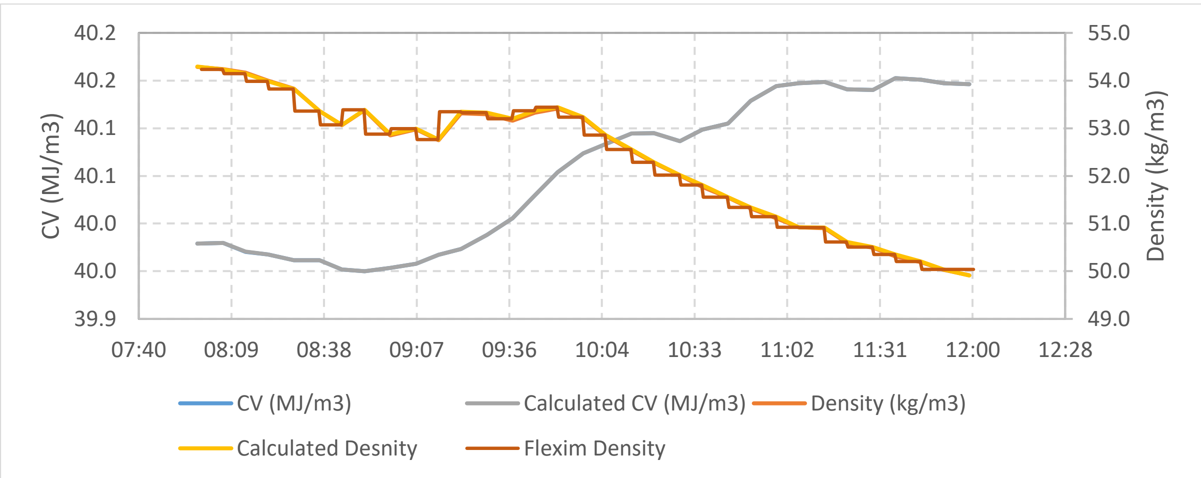

Figure 7: Flow Test 1 – CV and Density Checks

Also on the chart is the density used in the to establish the mass flow from the USM. The density has been taken to be the same as the orifice system. The stair case has been created because the USM meter stores data at a much higher freuency than the orifice. The density has been assumed to be constant between the orifice readings.

3.5 Flow Test 2 - Plate 295/5 Reverse Orientation

3.5.1 Orifice Details

The orifice details entered into the flow computer are the same as those for test 1 and are presented in Table 5 in Section 3.4.1

3.5.2 Orifice Installation Details

The orifice plate was removed and installed in the reverse orientation. Figure 8 and Figure 9 show the orifice orientation. The orifice is installed in the reverse orientation with the flow from left to right and the bevel on the upstream side and the sharp edge on the downstream side.

Figure 8: Flow Test 2 - Plate 1 (295/5) - Sharp Edge Downstream

Figure 9: Flow Test 2 - Plate 1 (295/5) – Bevel Upstream

3.5.3 Test Results

Flow was available from 08:00, however the flow test commenced at 09:00 with an indicated throughput of approximately 160,000sm3/h. Flow was available up until 13:00, however the site was informed of a compressor trip upstream at 11:20 and the flow did drop significantly before recovering. The flow between 09:00 and 12:00 was stable and has been selected as the period for this test.

A plot of the flow rate over the period is presented in Figure 10. This plot shows a number of trends.

The blue trend is the flow rate established from the totaliser from the Z0x file as described in section 3.3.1. The grey trend is the average flow rate established by calculating the average flow rate for all instantaneous readings from the Z0x file from the start of the test to the time it is plotted.

The orange trend shows the instantaneous readings taken from the Z0x file. The yellow trend is the Meter Factor corrected reading from the USM.

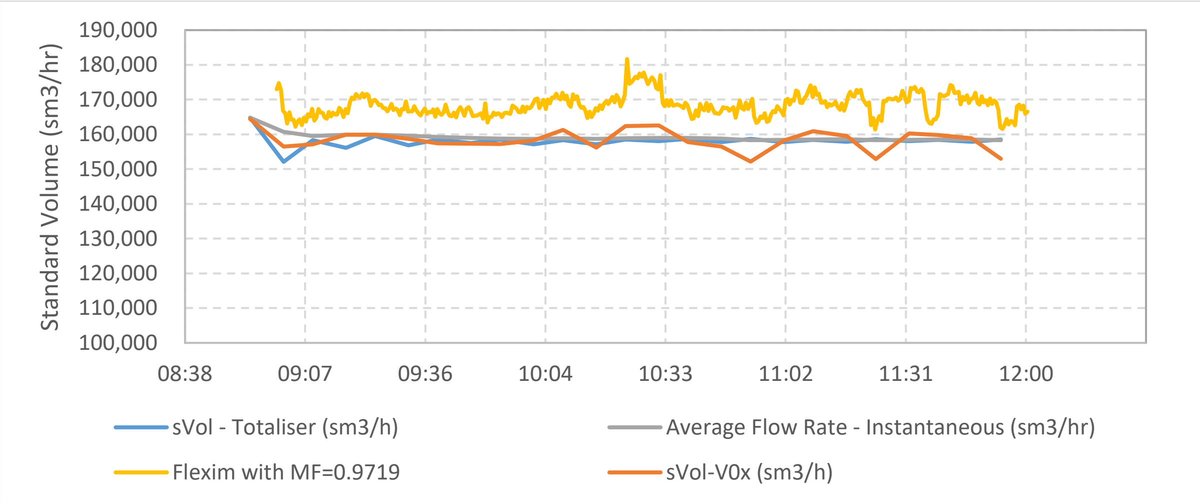

Figure 10: Flow Test 2 – USM and Orifice Flow Rates

The average flow rate has been calculated based on the totaliser and the instantaneous measured flow rates. The difference between these two figures is 0.14%. This is considered to be a reasonable resolution for the average flow rate for the test.

Table 7: Flow Test 2 – Average Flow Rates and Meter Factor

Description	Value	Unit
Orifice: Average Flow Rate (sm3/hr) - Instantaneous	158,325	sm3/hr
Orifice: Average Flow Rate (sm3/hr) - Difference Total	158,548	sm3/hr
Orifice: Difference - Total-Instantaneous	223.34	sm3/hr
Orifice: Difference - Total-Instantaneous	0.14%	%
USM: Average Flow Rate (sm3/hr) (Meter Factor Applied)	168,335	sm3/hr
Difference between Orifice and USM	-5.814%	%

Table 7 shows the average flow rates for the orifice and Meter Factor corrected USM over the test period. The difference between the USM and Orifice was -5.814%.

The orange trend in Figure 10 is the USM instantaneous reading after correction by the meter factor. It can be seen that the Orifice is persistently reading lower than the meter factor corrected USM. The difference is -5.814%

Figure 11 shows a trend of the instantaneous flow rate taken from the V0x file, the Z0x file and the flow rate calculated from the differential pressure from the V0x file. All data points are very close to one another providing confidence in the recorded data and the flow computer configuration and calculation.

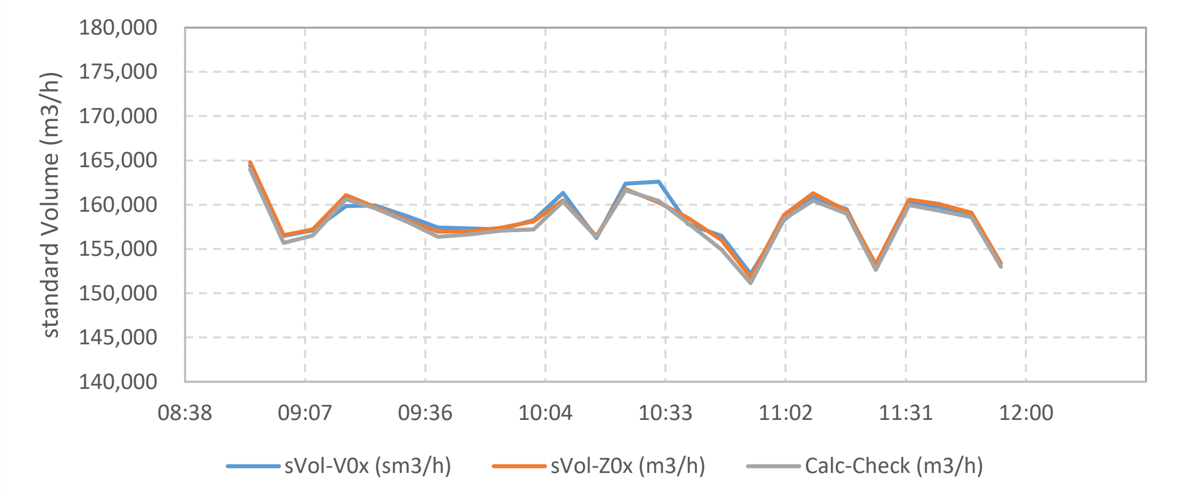

Figure 11: Flow Test 2 – Instantaneous Volume Flow Rates

Figure 12 shows the logged CV and Density from the Z0x file and the calculated values using ISO6976 and AGA8 calculations within excel based on the composition returned in the Z0x file. All values are coincident providing confidence in the logged data and the flow computer configuration.

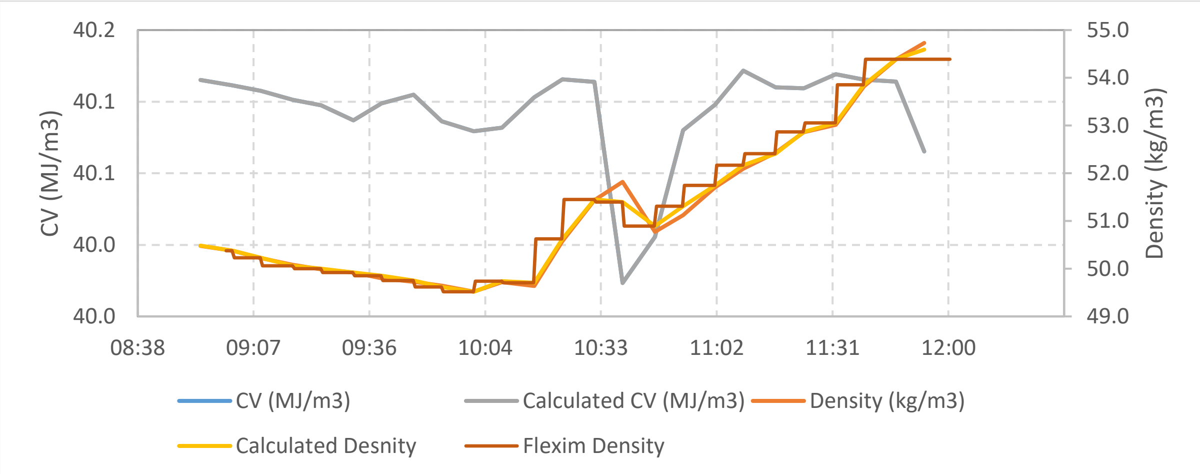

Figure 12: Flow Test 2 – CV and Density Checks

Also on the chart is the density used in the to establish the mass flow from the USM. The density has been taken to be the same as the orifice system. The stair case has been created because the USM meter stores data at a much higher freuency than the orifice. The density has been assumed to be constant between the orifice readings.

3.6 Flow Test 3 - Plate ARLE5036 Correct Orientation

3.6.1 Orifice Details

The orifice details entered into the flow computer were taken from the latest calibration certificate (BA7932) and are presented in Table 8 below.

Table 8: Orifice Plate Metrology – ARLE5036 – Cert BA7932

Calibration Certificate	DNV GL: BA7932	
Certificate Issue Date	13th May 2021	
Plate Identification	BA7932	
Laboratory Temperature	20.8	DegC
Measured Bore Diameter	309.9834	mm
Nominal Pipe Diameter	432.2096	mm
Nominal Beta Ratio	0.717206	-

(Note the CFD was based on an earlier calibration certificate).

3.6.2 Orifice Installation Details

Photographs of the orifice plates installation are provided in Figure 13. The orifice is installed in the correct orientation with the flow from left to right and the bevel on the downstream side.

Figure 13: Flow Test 3 - Installation of plate 2 (ARLE5036)

3.6.3 Test Results

Flow through the station started at 07:00 and the flow test commenced at 07:30 once the flow had stabilised at a throughput of approximately 160,000sm3/h and was completed by 11:10. The flow was stable throughout the flow test period.

A plot of the flow rate over the period is presented in Figure 14. This plot shows a number of trends.

The blue trend is the flow rate established from the totaliser from the Z0x file as described in section 3.3.1. The grey trend is the average flow rate established by calculating the average flow rate for all instantaneous readings from the Z0x file from the start of the test to the time it is plotted.

The orange trend are the instantaneous readings taken from the Z0x file. The yellow trend is the Meter Factor corrected reading from the USM.

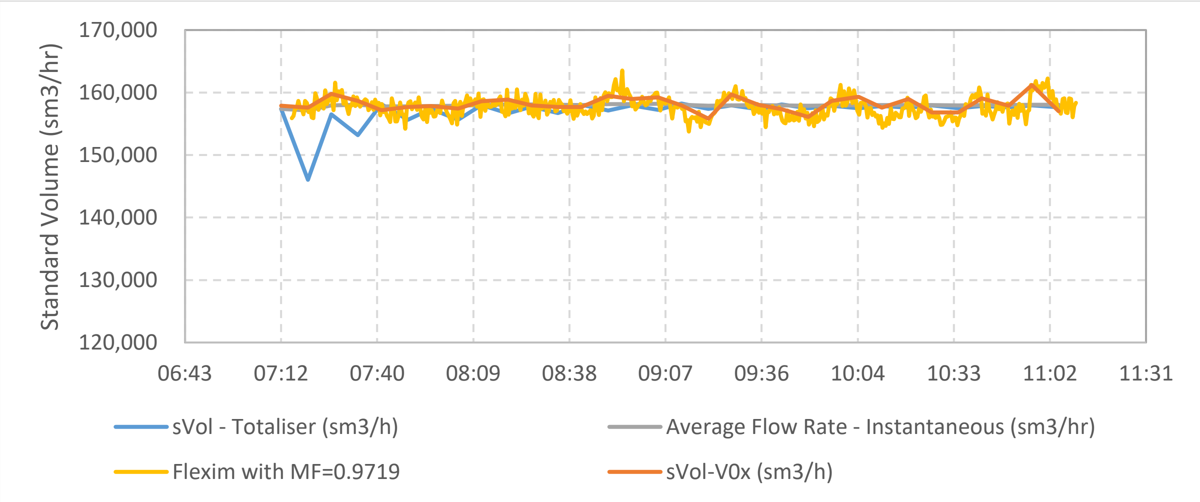

Figure 14: Flow Test 3 – USM and Orifice Flow Rates

The average flow rate has been calculated based on the totaliser and the instantaneous measured flow rates. The difference between these two figures is -0.27, this is considered to be a reasonable resolution for the average flow rate for the test based on the sample interval and test duration.

Table 9: Flow Test 3 – Average Flow Rates and Meter Factor

Description	Value	Unit
Orifice: Average Flow Rate (sm3/hr) - Instantaneous	158,039	sm3/hr
Orifice: Average Flow Rate (sm3/hr) - Difference Total	157,612	sm3/hr
Orifice: Difference - Total-Instantaneous	-427.58	sm3/hr
Orifice: Difference - Total-Instantaneous	-0.27	%
USM: Average Flow Rate (sm3/hr)	157,651	sm3/hr
Difference between Orifice and USM	-0.025	%
USM Meter Factor in use (from test 1)	0.9719	

Table 9 shows the average flow rates for the orifice and USM over the test period. The difference between the USM and Orifice was -0.025%, which demonstrates excellent reproducibility from the first flow test.

The orange trend in Figure 14 is the USM instantaneous reading after correction by the meter factor. It can be seen that the USM and Orifice are in very close agreement after the application of the meter factor.

Figure 15 shows a trend of the instantaneous flow rate taken from the V0x file, the Z0x file and the flow rate calculated from the differential pressure from the V0x file. All data points are very close to one another providing confidence in the recorded data and the flow computer configuration and calculation.

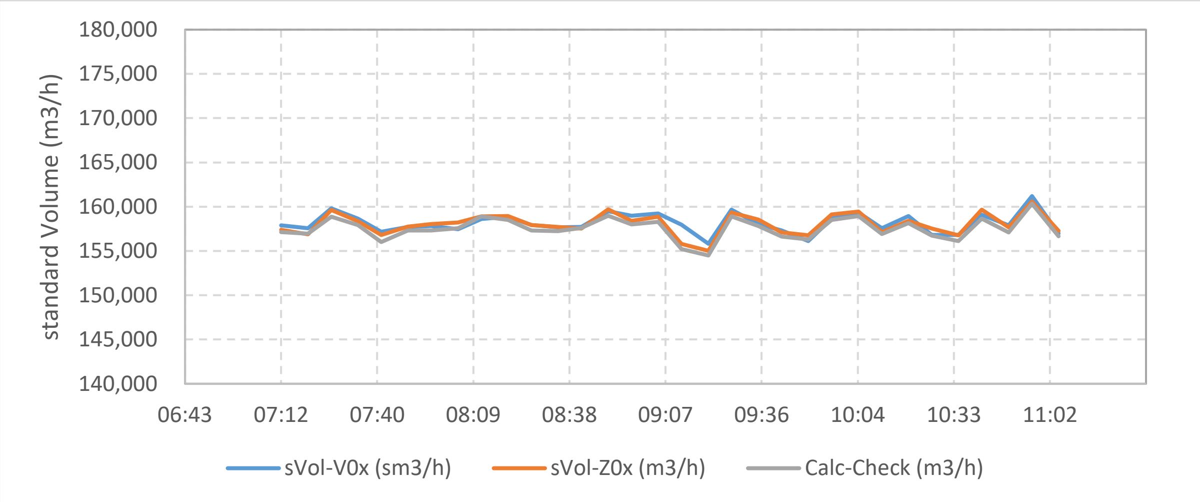

Figure 15: Flow Test 3 – Instantaneous Volume Flow Rates

Figure 16 shows the logged CV and Density from the Z0x file and the calculated values using ISO6976 and AGA8 calculations within excel based on the composition returned in the Z0x file. All values are coincident providing confidence in the logged data and the flow computer configuration.

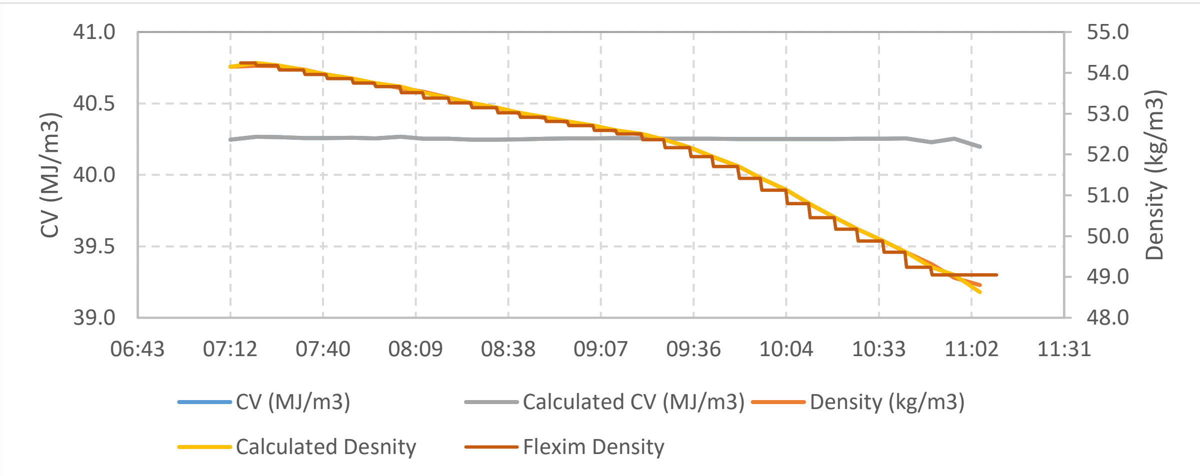

Figure 16: Flow Test 3 – CV and Density Checks

Also on the chart is the density used in the to establish the mass flow from the USM. The density has been taken to be the same as the orifice system. The stair case has been created because the USM meter stores data at a much higher freuency than the orifice. The density has been assumed to be constant between the orifice readings.

3.7 Flow Test 4 - Plate ARLE5036 Reverse Orientation

The orifice details entered in to the flow computer are the same as those for test 3 and are presented in Table 8 in Section 3.6.1

3.7.1 Orifice Installation Details

The orifice plate was removed and installed in the reverse orientation. Figure 17 and Figure 18 show the orifice orientation. The orifice is installed in the reverse orientation with the flow from left to right and the bevel on the upstream side and the sharp edge on the downstream side.

Figure 17: Flow Test 4 - Plate 2 (ARLE5036) - Sharp Edge Downstream

Figure 18: Flow Test 4 - Plate 2 (ARLE5036) – Bevel Upstream

3.7.2 Test Results

Flow was available from 08:00, and the flow test commenced at 08:15 with an indicated throughput of approximately 160,000sm3/h. Flow was available up until 12:15. The flow between 08:15 and 12:15 was stable and has been selected as the period for this test.

A plot of the flow rate over the period is presented in Figure 19. This plot shows a number of trends.

The blue trend is the flow rate established from the totaliser from the Z0x file as described in section 3.3.1. The grey trend is the average flow rate established by calculating the average flow rate for all instantaneous readings from the Z0x file from the start of the test to the time it is plotted.

The orange trend shows the instantaneous readings taken from the Z0x file. The yellow trend is the Meter Factor corrected reading from the USM.

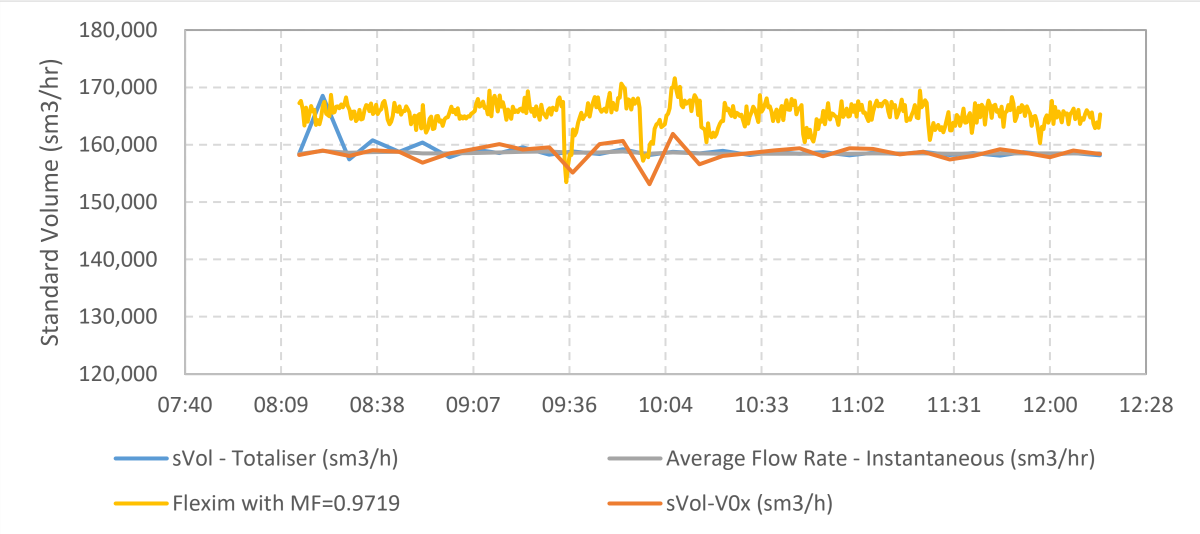

Figure 19: Flow Test 4 – USM and Orifice Flow Rates

The average flow rate has been calculated based on the totaliser and the instantaneous measured flow rates. The difference between these two figures is -0.2%. This is considered to be a reasonable resolution for the average flow rate for the test based on the duration and sample interval.

Table 10: Flow Test 4 – Average Flow Rates and Meter Factor

Description	**Value**	**Unit**
Orifice: Average Flow Rate (sm3/hr) - Instantaneous	158,487	sm3/hr
Orifice: Average Flow Rate (sm3/hr) - Difference Total	158,178	sm3/hr
Orifice: Difference - Total-Instantaneous	-309.82	sm3/hr
Orifice: Difference - Total-Instantaneous	-0.2%	%
USM: Average Flow Rate (sm3/hr) (Meter Factor Applied)	165,326	sm3/hr
Difference between Orifice and USM	-4.324%	%

Table 10 shows the average flow rates for the orifice and Meter Factor corrected USM over the test period. The difference between the USM and Orifice was -4.324%.

The orange trend in Figure 19 is the USM instantaneous reading after correction by the meter factor. It can be seen that the Orifice is persistently reading lower than the meter factor corrected USM. The difference is -4.324%

Figure 20 shows a trend of the instantaneous flow rate taken from the V0x file, the Z0x file and the flow rate calculated from the differential pressure from the V0x file. All data points are very close to one another providing confidence in the recorded data and the flow computer configuration and calculation.

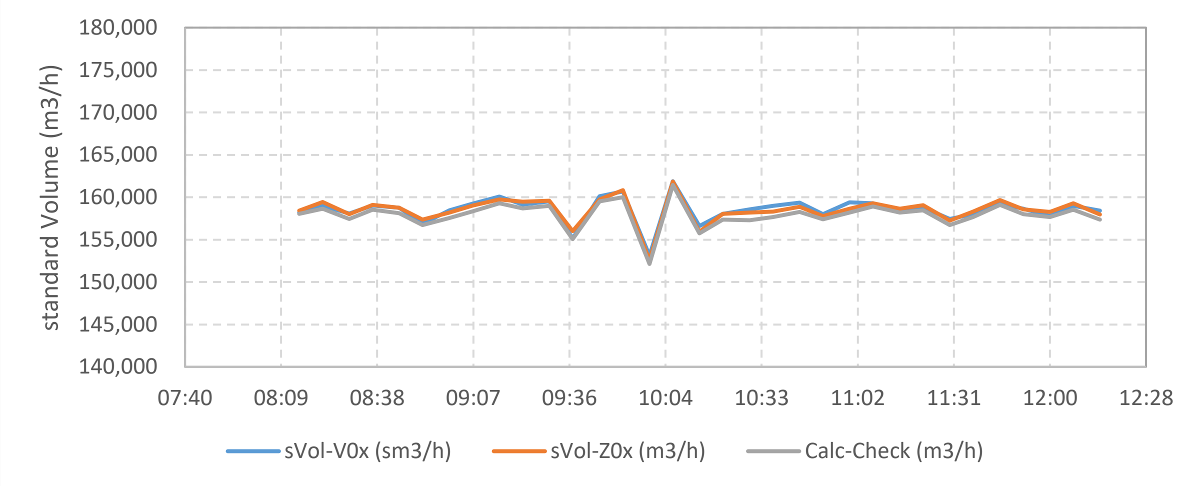

Figure 20: Flow Test 4 – Instantaneous Volume Flow Rates

Figure 21 shows the logged CV and Density from the Z0x file and the calculated values using ISO6976 and AGA8 calculations within excel based on the composition returned in the Z0x file. All values are coincident providing confidence in the logged data and the flow computer configuration.

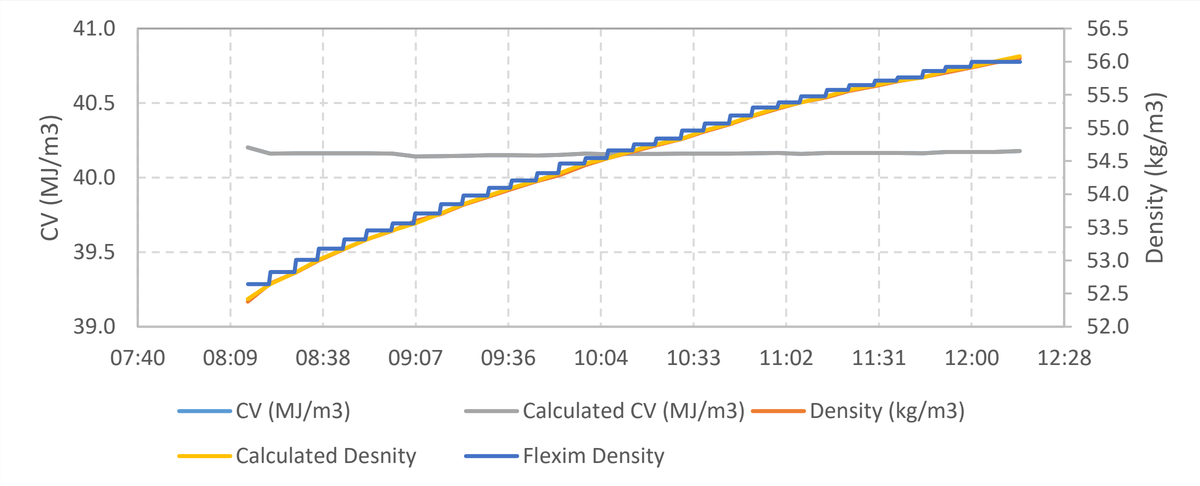

Figure 21: Flow Test 4 – CV and Density Checks

Also on the chart is the density used in the to establish the mass flow from the USM. The density has been taken to be the same as the orifice system. The stair case has been created because the USM meter stores data at a much higher freuency than the orifice. The density has been assumed to be constant between the orifice readings.