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Client	**:**	**SCOTIA GAS NETWORKS**
Project Title	**:**	**ABERDEEN MEASUREMENT ERROR REVIEW**
Document Title	**:**	**INDEPENDENT EXPERT SIGNIFICANT METER ERROR (SMER)**
Document Ref.	**:**	**NK3177 – 001**
Client Ref.	**:**	**1610074649**

REV	ISSUE DATE	DESCRIPTION	PREP. BY	APP. BY
1	16/08/13	Issue for Comment	KV	
2	20/09/13	Final – Agreed TMI Responses Added	KV	

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1.0 INTRODUCTION

This report details the work carried out by the Appointed Independent Technical Expert (Keith Vugler of KELTON®) to complete a technical evaluation of a Significant Meter Error Report (SMER) raised by Scotia Gas Networks (SGN) on their Aberdeen metering facility.

In accordance with the "Measurement Error Notification Guidelines for NTS to LDZ Measurement Installations" document V4, 21/07/11, the SMER technical evaluation report will incorporate the requirements of section 10 (Generic Terms for an Appointed Independent Technical Expert), section 14 (Business Rules for the Compilation of a SMER) and additionally the Terms of Reference (TOR) agreed at the Off-take Arrangements Workgroup on the 1st March 2011

The review & report deliverables are therefore interpreted as follows;

Individually and independently;

- Define the technical methodology to derive a robust evaluation of the magnitude of the SMER
- Define the data requirements (supportive data) of the SMER
- Provide detailed data rules (for the evaluation methodology of the SMER)
- Define the technical evidence used in the evaluation methodology of the SMER
- Define the SMER period
- Application of the defined methodology in quantifying the SMER
- Presentation of the defined methodology to the technical work stream
- Issue of a draft report to the Off-take Arrangements Workgroup for comment

Collectively (with the second Appointed Independent Technical Expert);

- Once the individual draft reports have been submitted and feedback from the Off-take Arrangements Workgroup has been provided, the two appointed Independent Technical Expert shall meet to discuss and produce a summary report which will identify any material differences in the individual reports, the processes employed, the data used and propose a single conclusion together with the justification for that conclusion.

2.0 EXECUTIVE SUMMARY

Section 3.0 of this report provides an overview of the SMER and confirms (with supportive data) the start and finish dates (and timings) of the SMER period(s).

There are two separate SMER periods that can be categorised for this review process;

1. 21st July 2009 (16:03 hours) to 27th July 2010 (17:22 hours)
2. 27th July 2010 (17:23 hours) to 10th August 2010 (13:10 hours)

It must be recognised that unlike the methodologies available to define a measurement error that is associated with an incorrect numerical factor or indeed a "well defined" systematic bias which can be relatively precise in its retrospective calculation of the error, the cause of the Aberdeen SMER requires a more practical approach which will at best, be an informed estimate.

As the effect(s) of the cause cannot be quantified by substituting a corrective parameter within say a flow rate algorithm, the requirement to perform a series of controlled site tests, to replicate the cause and effect(s) under the same (or very similar) operational conditions seen during the SMER period was identified by the Appointed Independent Expert as the most appropriate technical methodology.

A site test procedure was developed (section 5.3 refers) and implemented at site on 2 separate occasions (covering 3 days and providing a total of 10 individual tests) to ensure a representative coverage of the operational conditions seen during the SMER period(s).

In addition, to provide an evaluation process for which the site testing results can be "trended", a totally independent Computational Fluid Dynamics (CFD) review has been completed by Professor Malalasekera of Loughborough University, which in turn was peer reviewed by the Modelling & Simulation Team at TUV SUD NEL (Section 8 refers).

The SMER errors have been calculated as an under-read of;

- SMER Period 1 (section 9.0 refers);
  - For Low flow days – Appendix E refers (<0.8 MMSm^3/d) = 25.114%
  - For Mid flow days – Appendix E refers (0.8 – 2.2 MMSm^3/d) = 27.630%
- SMER Period 2 = 70.554% (section 9.0 refers)

It is the recommendation of this report that the following correction factors be applied to the Gemini daily totals of the SMER periods in accordance with section 10.0 of this report;

- SMER Period 1;
  - For Low flow days = 1.335
  - For Mid flow days = 1.382
- SMER Period 2 = 3.396

The size of the error is estimated to be 1,704 GWh under-registration.

The cause of the Aberdeen SMER is confirmed to be the result of the incorrect positioning of the orifice plate within the orifice carrier following routine inspection visits.

It transpired that following a visit on the **21st July 2009** to inspect and change-out the orifice plate in accordance with annual ME2 requirements, the orifice plate was not positioned correctly within the orifice carrier.

It would appear that the mitigating circumstances leading to this event were two fold;

1. The visual condition of the counter reading window which restricted the ability to correctly view the full 5 digit display (Figure 3.1 below refers).

2. The misinterpretation of the required positional settings that are stamped on the orifice carrier data plate (Figure 3.2 over refers).

Figure 3.1 – Orifice Carrier Counter Assembly

Figure 3.2 – Orifice Carrier Data Plate

Additionally, during the next annual ME2 orifice plate inspection visit on the **27th July 2010**, the orifice plate was again positioned incorrectly within the orifice carrier following completion of the procedural inspection activities but this time at a different counter reading than that of 21st July 2009.

Finally, during an emergency intervention visit on the **10th August 2010**, the incorrect orifice position was detected and rectified accordingly.

The result of these incorrect orifice plate positions therefore creates two separate SMER periods;

1. **21st July 2009 to 27th July 2010**
2. **27th July 2010 to 10th August 2010**

Two "key" factors require confirmation;

A. For each SMER period - The actual date and time that the "in error" metering data commenced for daily reporting purposes within Gemini and the actual date and time the "in error" metering data was subsequently identified as being "valid".

B. For each SMER period - The "as left" orifice carrier counter reading(s).

For the SMER period (1);

It can be confirmed from the independent review that the orifice plate inspection activity took place during the 21st July 2009 as it is well documented within the ME2 reporting form CP14(a) below;

CP14a - ORIFICE PLATE INSPECTION/REPLACEMENT - Stream 1.

Equipment under test			Site	ABERDEEN	
Flow Computer			Tag No	Stream1	
Orifice Plate Check	Tol	Pass/Fail	Serial No	050/2	
ORIFICE PLATE DETAILS STREAM1					
Removed Plate			**New Plate (if applicable)**		
Manufacturer	Unknown		Manufacturer	Unknown	
Serial Number	050/4		Serial Number	050/2	
Certified Bore	177.2103	mm	Certified Bore	176.9349	mm
Calibration Temp	19.8	C	Calibration Temp	19.9	C
Certifying Authority	ANTECH		Certifying Authority	ANTECH	
Certificate Number	U27810-07		Certificate Number	U32969-08	
Certificate Date	10/05/07		Certificate Date	09/09/08	
ORIFICE PLATE INSPECTION (Removed plate)					
Orientation of Plate Checked and Found Correct:				Yes	
Orifice Plate Carrier Operation Inspected and Found Satisfactory:				Yes	
Orifice Plate Inspected Visually and is:					
Flat				Yes	
No Sign of Wear				Yes	
No Surface Marks				Yes	
Square Edged				Yes	
Clean				Yes	
DATA MODIFICATIONS (for new plate/site re-range)					
Station Flow Max Change?			New Station Max Flow		mscmd
Pulse Significance Change?			New Pulse Significance		scm
a) OMNI Updated?			New Station Max Flow		scm/hr
			New Pulse Significance		pulses/unit
			New Orifice Bore		mm
			New Low DP Span		mBar
			New High DP Span		mBar
b) ACC Informed?			New Station Max Flow		mscmd
			New Pulse Significance		scm
c) NJEX Controller Updated?			New Station Max Flow		scm/s
d) Telemetry Unit Relabelled?					
e) Other Signals Updated?					
STATUS					
Completed and Satisfactory	Yes				
Status	Pass				
COMMENTS					
SIGNATURES					
Date	21-Jul-09		Equipment Reinstated?	Yes	YES/NO
Tested By	Peter McQueen.		and	Sandy Slater.	
Approved By	Cameron Moffat.				

Figure 3.3 – ME2 Form CP14(a) for 21/07/2009

What isn't so well documented is the "as left" orifice carrier counter reading following completion of the orifice plate replacement as there is not a procedural requirement to record this on any form or logbook.

From internal site investigative work performed by SGN, site flow data charts taken from the 21st July 2009 (showing the step change in flow before and after the orifice plate change out) were used to correlate a relative orifice position and hence a counter reading value. The results of these tests concluded that the "as left" counter position could have potentially been between 99984 and 99975.

From an independent review of these results and from further discussions with the personnel involved, the most logical counter reading (in the opinion of the Appointed Independent Technical Expert) within this range would be **99985**.

The rationale behind this is that given the mitigating circumstances identified on page 3 of this document and the fact that the value of 99885 is stamped on the data plate as the value for a fully removed plate position (Figure 3.2 refers), it is quite conceivable that the Maintenance Technician interpreted the whole process incorrectly and ended up at a counter position of 99985. None of the other readings would have had any practical relevance in which to "aim", for any other particular counter reading.

The graph in Figure 3.4 over page, populated with 4-minute rbd data for the 21st July 2009 shows the "before" and "after" flow deviation that resulted from the orifice plate change-out activity.

It can be seen that the site maintenance activities commenced on the morning of 21st July 2009 and the Aberdeen station flow rate was manually "set" at the observed "on-line" flow rate of 0.72 MMSm3/d at 10:44.

On completion of all site maintenance activities, the manually "set" flow rate was released and the flow rate indication dropped to typically 0.5 MMSm3/h at 16:03.

Given that the procedural requirement is for the station flow to remain steady throughout the period of maintenance intervention, the assumption is that a flow rate indication error was introduced post orifice plate inspection of typically 30% (under-read).

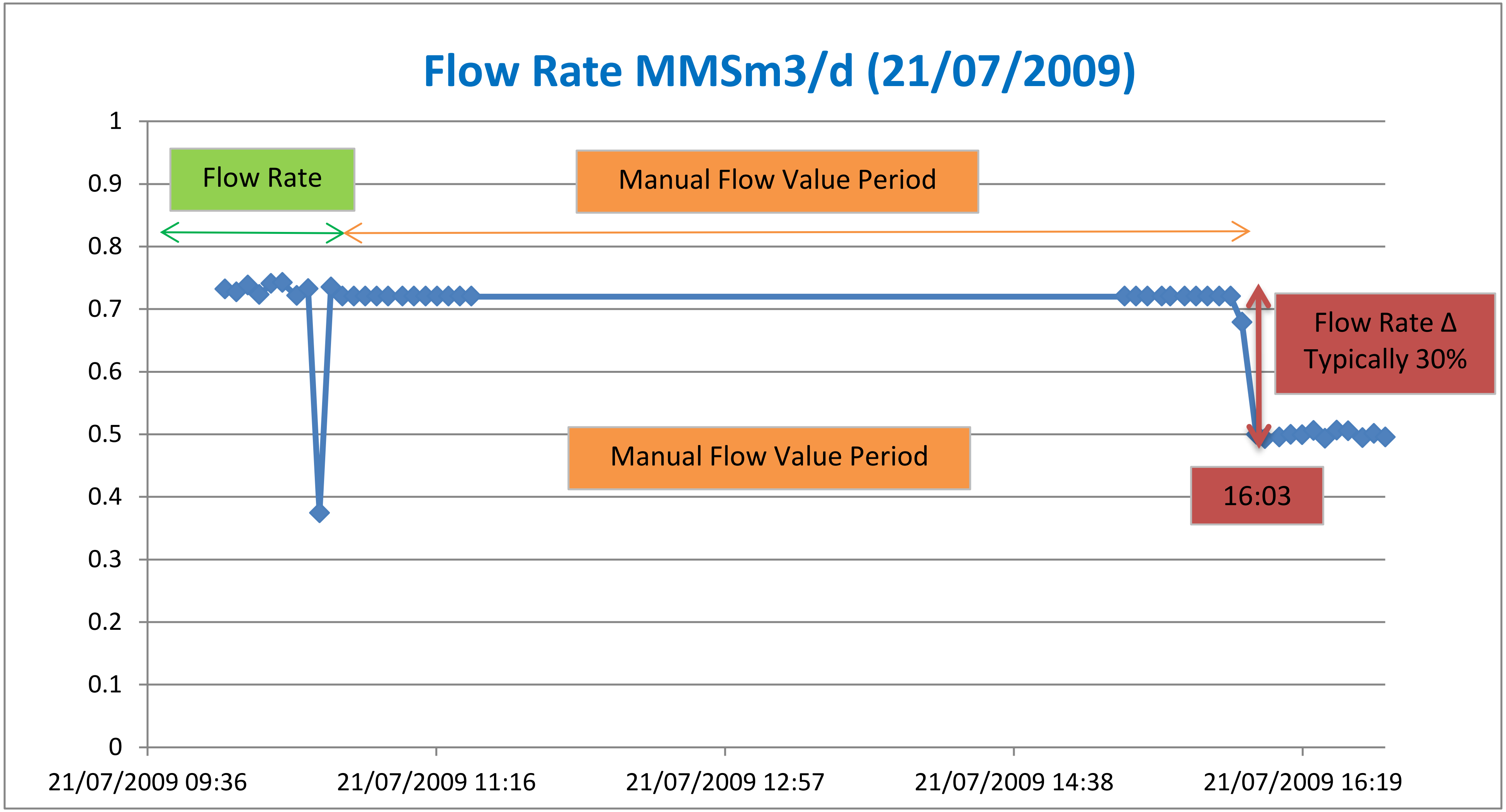


Figure 3.4 – Aberdeen Flow Data for 21/07/2009

For the SMER period (2);

It can be confirmed from the independent review that the orifice plate inspection activity took place during the 27th July 2010 is as it is well documented within the ME2 reporting form CP14(a) below;

CP14a - ORIFICE PLATE INSPECTION/REPLACEMENT - Stream 1.

Equipment under test			Site	ABERDEEN	
Flow Computer			Tag No	Stream1	
Orifice Plate Check	Tol	Pass/Fail	Serial No		
ORIFICE PLATE DETAILS STREAM1					
Removed Plate			**New Plate (if applicable)**		
Manufacturer	Unknown		Manufacturer	Unknown	
Serial Number	050/2		Serial Number	050/4	
Certified Bore	176.9349	mm	Certified Bore	177.2128	mm
Calibration Temp	19.9	C	Calibration Temp	20.2	C
Certifying Authority	ANTECH		Certifying Authority	ANTECH	
Certificate Number	U32969-08		Certificate Number	U39509-09	
Certificate Date	09/09/08		Certificate Date	11/12/09	
ORIFICE PLATE INSPECTION (Removed plate)					
Orientation of Plate Checked and Found Correct:				Yes	
Orifice Plate Carrier Operation Inspected and Found Satisfactory:				Yes	
Orifice Plate Inspected Visually and is:					
Flat				Yes	
No Sign of Wear				Yes	
No Surface Marks				Yes	
Square Edged				Yes	
Clean				Yes	
DATA MODIFICATIONS (for new plate/site re-range)					
Station Flow Max Change?			New Station Max Flow		mscmd
Pulse Significance Change?			New Pulse Significance		scm
a) OMNI Updated?			New Station Max Flow		scm/hr
			New Pulse Significance		pulses/unit
			New Orifice Bore		mm
			New Low DP Span		mBar
			New High DP Span		mBar
b) ACC Informed?			New Station Max Flow		mscmd
			New Pulse Significance		scm
c) NJEX Controller Updated?			New Station Max Flow		scm/s
d) Telemetry Unit Relabelled?					
e) Other Signals Updated?					
STATUS					
Completed and Satisfactory	Yes				
Status	Pass				
COMMENTS					
SIGNATURES					
Date	27-Jul-10		Equipment Reinstated?	Yes	YES/NO
Tested By	Peter McQueen.		and	Piotr Wolak	
Approved By	Billy Pollock.				

Figure 3.5 – ME2 Form CP14(a) for 27/07/2010

Unlike the SMER period (1), the "as left" orifice carrier counter reading following completion of the orifice plate replacement has some confidence attached in that the personnel involved "remember" that the "as left" counter reading value was 99995, however this is not supported by any traceable records reported on any form or logbook.

From discussions with the personnel involved, they seemed confident that their normal approach to this activity was to wind (or rack) the orifice plate down to the required position identified on the manufacturers' instructions which in this case was 99995 – 00005 for a fully seated orifice plate assembly.

It should be noted that that this 99995 – 00005 counter value guidance is not physically stamped on the orifice carrier data plate (Figure 3.2 refers) and it is understood that the orifice carrier manufacturer (FMC Energy Systems) have not recognised these values as a standard guidance that they would generally provide.

Again, given the mitigating circumstances identified on page 3 of this document, what appears to have happened on this occasion is that the Maintenance Technician Team followed their usual procedure in looking to "aim" for a counter reading of 99995 but due to the restricted ability to correctly view the full 5 digit display, ended up at **99950**.

This counter position is further supported by the events of the next visit of the 10th August 2010 (in response to a generated Fault Log raised on 7th August 2010).

From further discussions with the personnel involved, the orifice plate was once again removed for inspection. However, this time the Senior Network Technician requested that the Maintenance Team ensured that the orifice plate assembly was fully seated by winding (or racking) until it would not move any further. The "as found" position was again noted as 99995 and additional information suggests that it required approximately an additional 14 turns before it became fully seated. This can be relatively well supported by referencing the FMC Site Measurement Report (Appendix C refers) and using a typical counter ratio of 3.5 to a single turn of the orifice plate assembly shaft.

What is confirmed in a written report by the Senior Network Technician is that on completion of the 10th August 2010 site activities the orifice carrier counter reading was left at 00000 and checked to be fully seated (Figure 3.6 refers to the SGN recorded text).

The graphs in Figures 3.7 and 3.8, populated with 4-minute rbd data for the 27th July 2010 and 10th August 2010 respectively show the "before" and "after" flow deviation that resulted from each of the orifice plate change-out/inspection activities.

From Figure 3.7 it can be seen that the site maintenance activities commenced on the morning of 27th July 2010 and the Aberdeen station flow rate was manually "set" at the observed "on-line" flow rate of 0.48 MMSm3/d at approximately 09:16.

On completion of the orifice plate inspection activity at 11.28, the manually "set" flow rate was released and following a period of zero indicated flow (understood to have been as a result of other on-going maintenance activities) increased initially to 0.29 MMSm3/d at 11:52 and settled back to 0.22 MMSm3/d at 12:29 before another period of zero flow indication was experienced (again, understood to have been as a result of other on-going maintenance activities).

The net flow difference at this juncture (Δ1) was typically 40% (under-read).

The initial feedback from the Senior Network Technician on site on 10th August is contained within an email dated 11th August 2010 as follows:-

> Further to our telephone conversations yesterday my findings were as follows.
>
> After investigating all other metering equipment / flowcomputer configuration etc. and deciding all was in order with them I turned my attention to the orifice plate. I already suspected the orifice plate as the problems on site appear to have started from the 27th July; the orifice plate was changed that day. Unfortunately due to site conditions we could not flow the site on completion of this work.
>
> When the orifice plate was removed on the 27th the mechanical team had noted the counter on the orifice plate carrier was reading 9995, the new plate was returned to this position. Yesterday we took the metering off line and removed the orifice plate for inspection, all was in order and the plate was replaced. Instead of returning the plate to 9995 as before I asked the mechanical guys to wind the plate fully down to 0000. I reinstated the metering and checked the DP across the head cells at this point. The valves were in DVC and frozen in local control therefore the flow remained constant throughout these tests. With the orifice plate at 0000 the DP was approx. 54mB and the flow 1.4 MSCMD. I asked the mechanical team to wind the plate back up to 9995 (I am not sure how many turns this took as I was inside at the flow computer at this time) the DP went back down to 6.1 mB and the flow to 0.5 MSCMD. I asked for the plate to be returned to 0000 and called you at this stage. The plate remains in this 0000 position.
>
> When the mechanical team replace the plate at this site they follow the instructions as stated on the carrier plate and they wind it down to the required position only i.e. 9995, they do not take right down to the bottom and back up to 9995.
>
> Hope this clarifies what was found yesterday.
>
> Yours.
>
> Senior Network Technician (Instrumentation)

Other conversations confirm that the orifice plate was positioned at a counter reading of 99950 rather than 9995 as specified in this email.

It is understood that the Mechanical Operative reported that the orifice plate elevator screw turned 14 times when lowering the orifice plate from a counter reading of 99950 to 00000 when correcting the fault on 10th August 2010.

Subsequent interviews were held with the Mechanical Operatives who undertook the orifice plate changes on 21st July 2009 and 27th July 2010. The Operatives were not able to confirm the counter reading on the orifice plate carrier at the end of the operations on 21st July 2009 or at the start of the operations on 27th July 2010. However, there is some confidence that the orifice plate was left at a counter reading of 99950 on 27th July 2010.

Further investigations were held on site on 6th September 2010 and these are detailed in Appendix 2.

From the evidence available it is quite clear that the orifice plate was located at a counter reading of 99950 between 27th July 2010 and 10th August 2010.

Figure 3.6 – Counter Position Recorded Text (SGN)

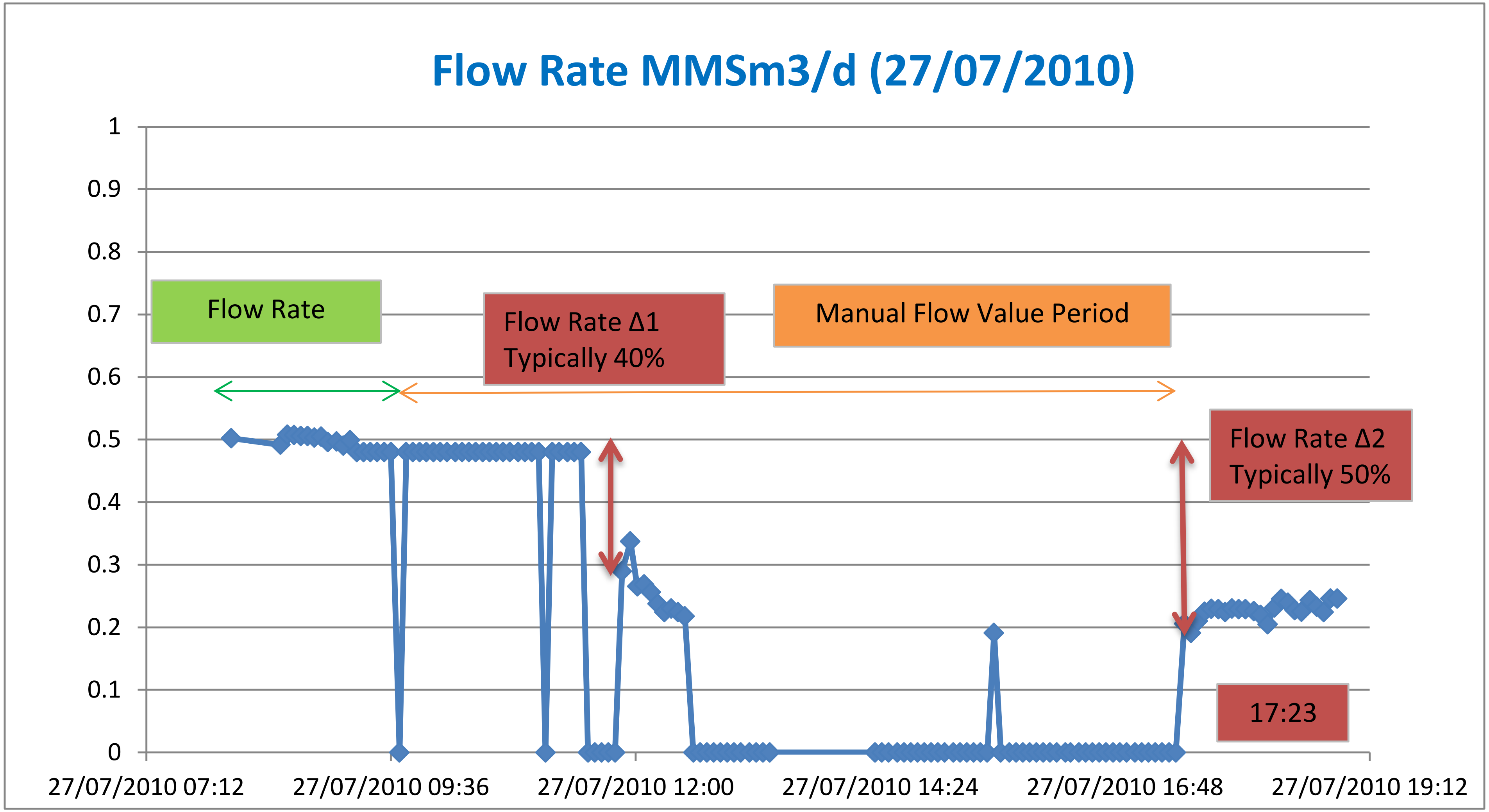


Figure 3.7 – Aberdeen Flow Data for 27/07/2010

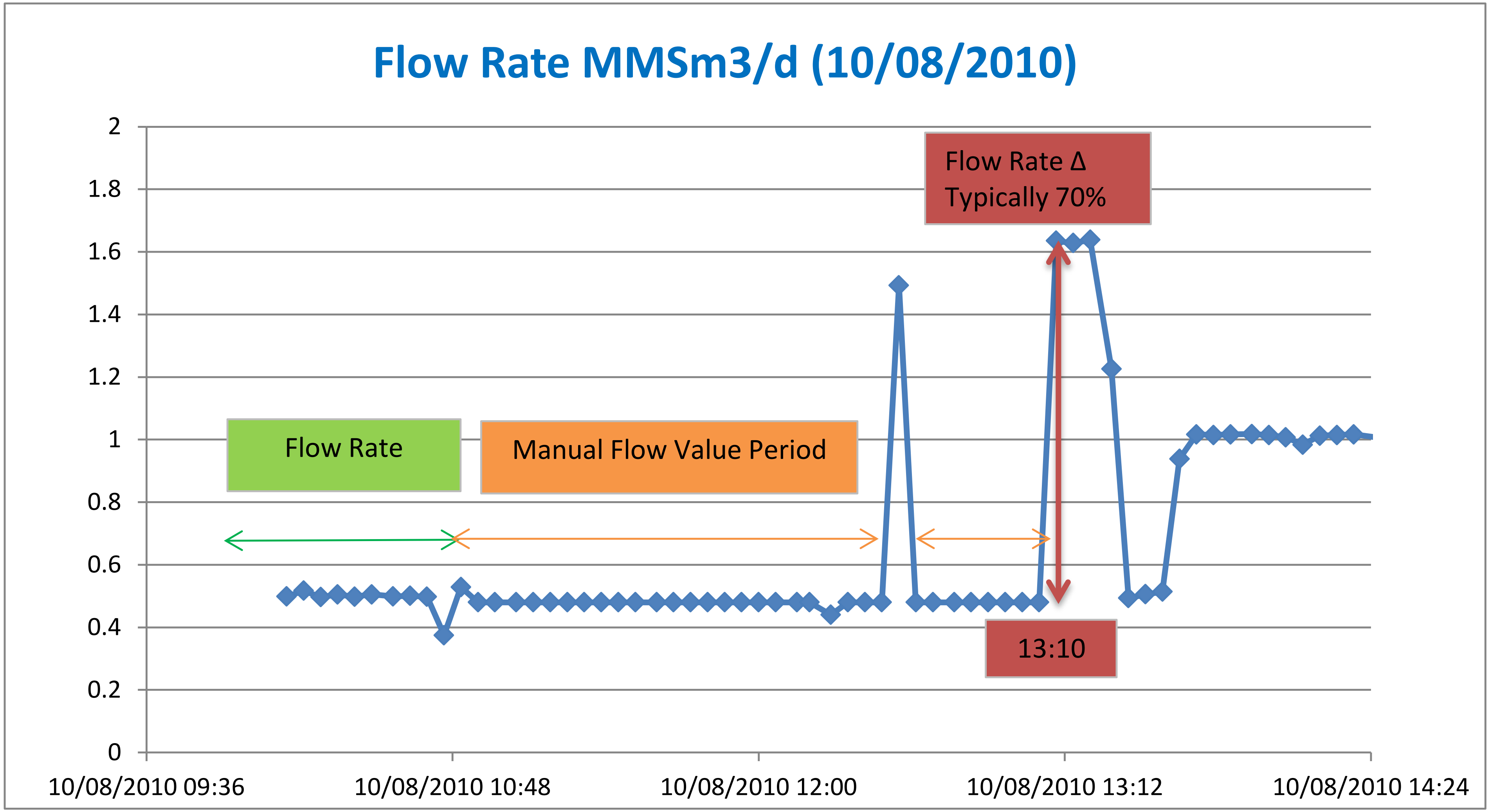


Figure 3.8 – Aberdeen Flow Data for 10/08/2010

On reinstatement of the flow data communications at 17.23, the flow rate indication increased to initially 0.2 MMSm3/d and settled out to an average of 0.23 MMSm3/d for the next two hour period.

The net flow difference at this juncture (Δ2) was typically 50% (under-read).

It seems logical however (but certainly not definitive), that given the procedural requirement for the station flow to remain steady throughout the period of maintenance intervention (which in this case was the orifice plate inspection activity between 09:16 and 11:28), the effect of the incorrect positioning of the orifice plate on the station flow rate is more aligned to the under-read value seen for Δ1.

Finally, it can be seen from Figure 3.8 that the site maintenance activities commenced on the morning of 10th August 2010 and the Aberdeen station flow rate was manually "set" at the observed "on-line" flow rate of 0.48 MMSm3/d at approximately 10:54.

On completion of all site maintenance activities, the manually "set" flow rate was released and flow increased to 1.635 MMSm3/d at 13:10.

Once again, given that the procedural requirement is for the station flow to remain steady throughout the period of maintenance intervention, the assumption is that a flow rate difference (over-read) was introduced post orifice plate inspection of typically 70%.

Information shown within Figures 3.4, 3.7 and 3.8 therefore suggest that the 2 separate periods relating to the total SMER review are;

For the SMER period (1) – Counter Position 99985;

- **Start – 16:03 hours on 21st July 2009**
- **Finish – 17:22 hours on 27th July 2010**

For the SMER period (2) – Counter Position 99950;

- **Start – 17:23 hours on 27th July 2010**
- **Finish – 13:10 hours on 10th August 2010**

Figure 4.1 – Site Layout

4.0 SYSTEM DESCRIPTION

The Aberdeen metering system comprises a single 10" meter run fitted with a HEECO International "Senior" type (dual chamber) orifice fitting.

Figure 4.2 – Senior Orifice Fitting

The meter run has a total upstream straight length of approximately 53 pipe diameters (D) after which the pipe goes underground by means of a 45^{o} bend. 21D upstream of the orifice fitting is a spool piece (2D in length - potentially incorporating a flow straightening device) and then a further 20D to a full bore inlet isolation valve.

Figure 4.3 – Upstream Pipe Section

Immediately downstream of the orifice fitting there is a flanged spool section of straight pipe approximately 6D long, the pipe continues for a further 12D to a 90° bend and then continues until the pipe goes underground by means of a 45° bend (figure 4.1 refers).

A 4-wire RTD temperature element is installed in an insertion pocket approximately 9D downstream of the primary device outlet flange.

Figure 4.4 – Downstream Pipe Section

The upstream and downstream straight lengths, including the orifice fitting and temperature flange are not insulated. An orifice plate with β = 0.69 was installed at the time of the site benchmarking visit (30th November 2011).

Differential pressure (ΔP) is measured by two high range and a single low range transmitter (calibrated 0-1000 and 0-100 mbar respectively). The high range ΔP transmitters are operated in duty/standby mode. The ΔP transmitters are isolated with a single 5-valve manifold with a single equalising valve. A single pressure transmitter (calibrated range 0-80 BarG) is used to measure line pressure. All transmitters are installed on a mounting rack assembly inside a walk-in enclosure (Figure 4.5 refers).

The pressure impulse lines are installed with a fall to the orifice fitting tappings. The impulse lines are not insulated (Figure 4.6 refers).

Figure 4.5 – Transmitter Mounting Rack

Figure 4.6 – Transmitter Impulse Lines

All transmitters communicate with a single dedicated OMNI flow computer installed in the site computer/communications room.

Figure 4.7 – Metering Panel

Sample gas is taken from an underground tapping point.

The sample gas is conditioned using a two stage pressure let-down system installed within a dedicated enclosure. The sample line is routed from the cabinet to a nearby Daniel Series 500 on-line gas chromatograph (OGC).

The OGC is installed within a dedicated analyser house with thermostatically controlled heating. The associated 2551 controller is installed in the OMNI flow computer rack.

The OMNI flow computer is used to calculate Relative Density (RD) and Calorific Value (CV) from gas composition, derived by the OGC, in accordance with ISO 6976:1995(E). Density is calculated, using the full gas composition from the OGC with live pressure and temperature, in accordance with AGA8:1994 Detailed Method. Flow rate is calculated in accordance with ISO 5167-1:1991(E).

The OGC is configured to auto calibrate daily against a test gas cylinder certified by EffecTech Ltd - UKAS accreditation 0590 - located in a section of the analyser house. Sample flow and pressures are monitored on a frequent basis by SGN personnel. In addition, an auto "35 day" calibration is performed against a specially prepared test gas mixture, which has been certified by OFGEM. The OFGEM local inspector visits the site "at least" every 3 months to witness the test.

Standard volume instantaneous flow rate and integrated flow in addition to an instantaneous CV measurement are re-transmitted to the regional SGN control facility via a locally installed telemetry unit. A metering database is also installed which provides a communications and metering data hub between the 2551 controller, OMNI 6000 flow computer and the telemetry unit. An ISDN link provides remote access to the metering database files for use by the HPMIS system server for review by SGN, OFGEM and NGG.

The metering system instrumentation and associated equipment are calibrated once every twelve months in accordance with the requirements of the SGN procedural document, ME2.

5.1 Introduction

Unlike the methodologies available to define a measurement error that is associated with an incorrect numerical factor (say an orifice plate or meter tube diameter) or indeed a well-defined systematic bias associated with a measuring device which can be relatively precise in its retrospective calculation of the error, the cause of the Aberdeen SMER required a more practical approach and would at best, be an informed estimate.

As the effect(s) of the cause cannot be quantified by substituting a corrective parameter within say a flow rate algorithm, the requirement to perform a controlled site test, to replicate the cause and effect(s) under the same (or very similar) operational conditions seen during the SMER period was identified by the Independent Expert as the most appropriate technical methodology.

Firstly, the operating conditions recorded throughout the SMER period were catalogued as follows;

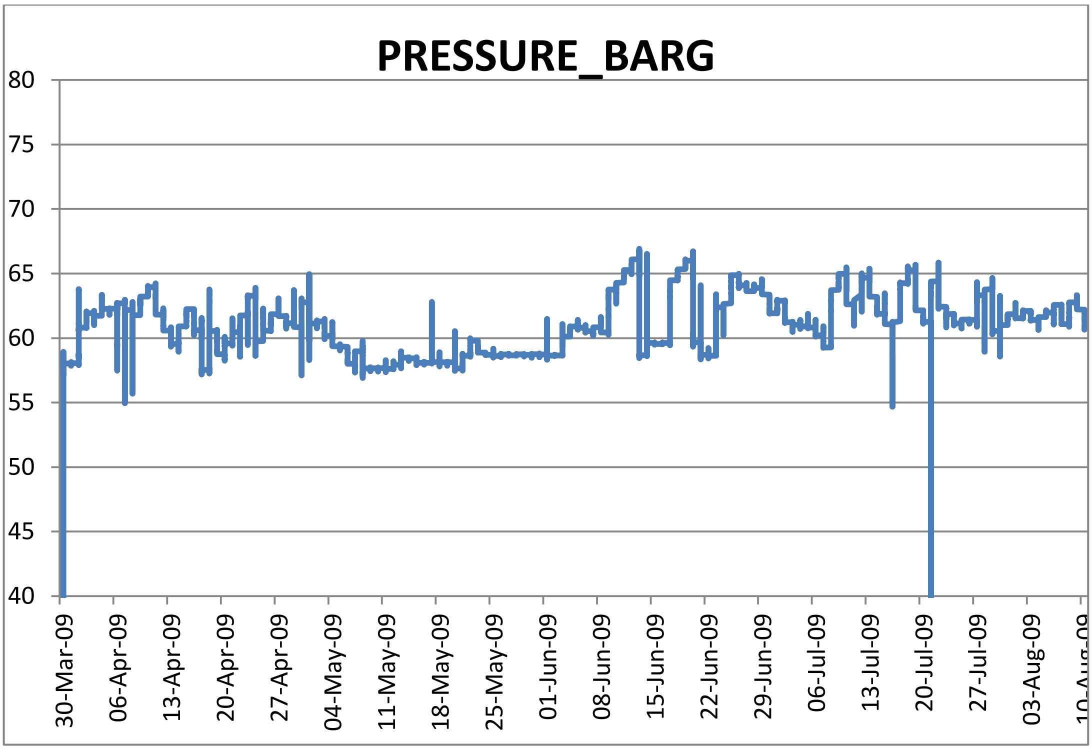


Figure 5.1.1 – SMER Period Pressure Variation (Apr to Aug 2009)

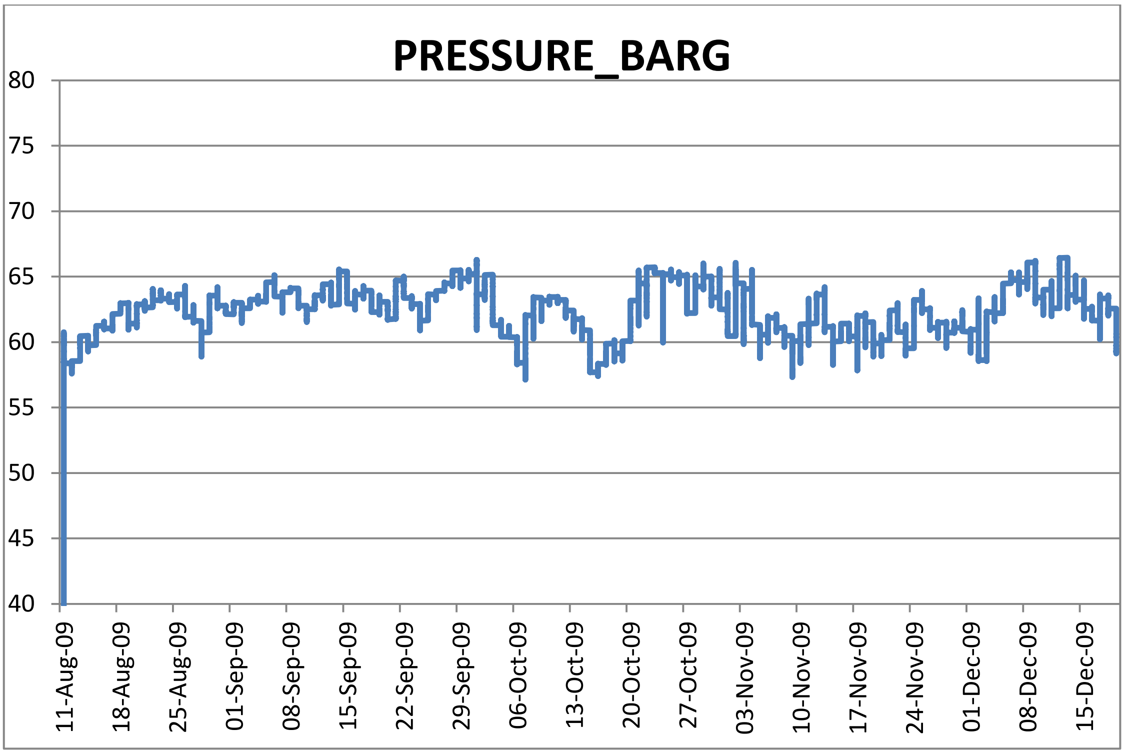


Figure 5.1.2 – SMER Period Pressure Variation (Aug to Dec 2009)

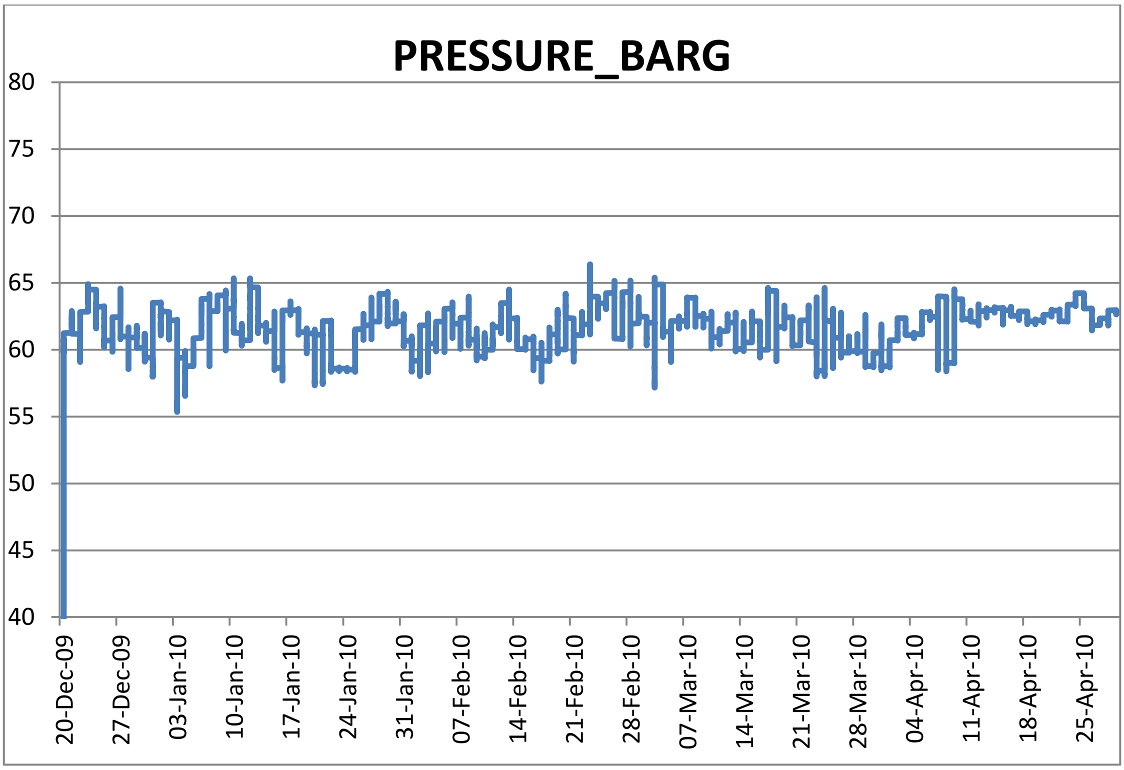


Figure 5.1.3 – SMER Period Pressure Variation (Dec 2009 to Apr 2010)

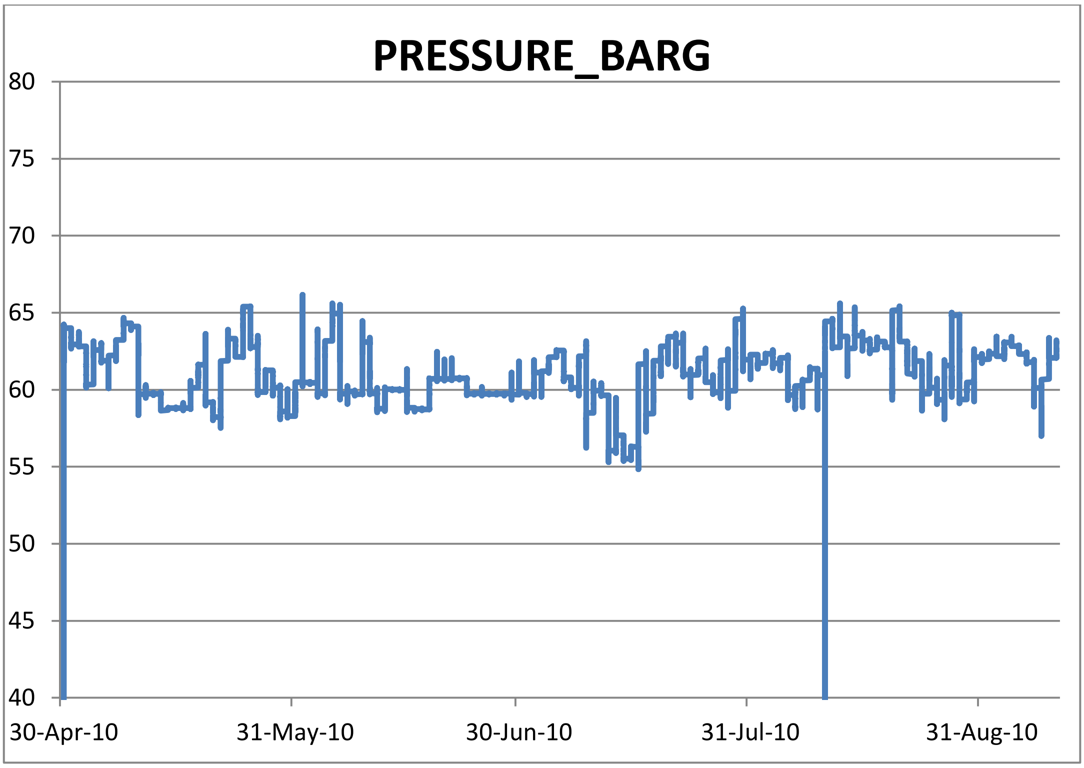


Figure 5.1.4 – SMER Period Pressure Variation (Apr to Sep 2010)

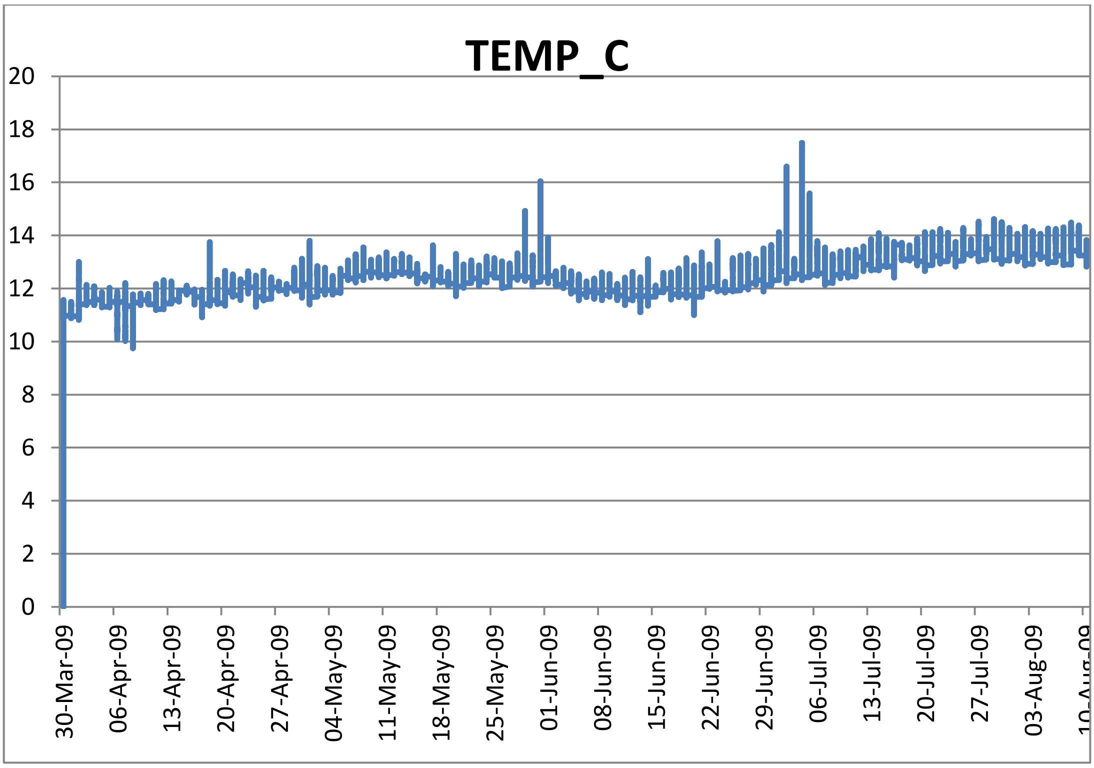


Figure 5.1.5 – SMER Period Temp Variation (Apr to Aug 2009)

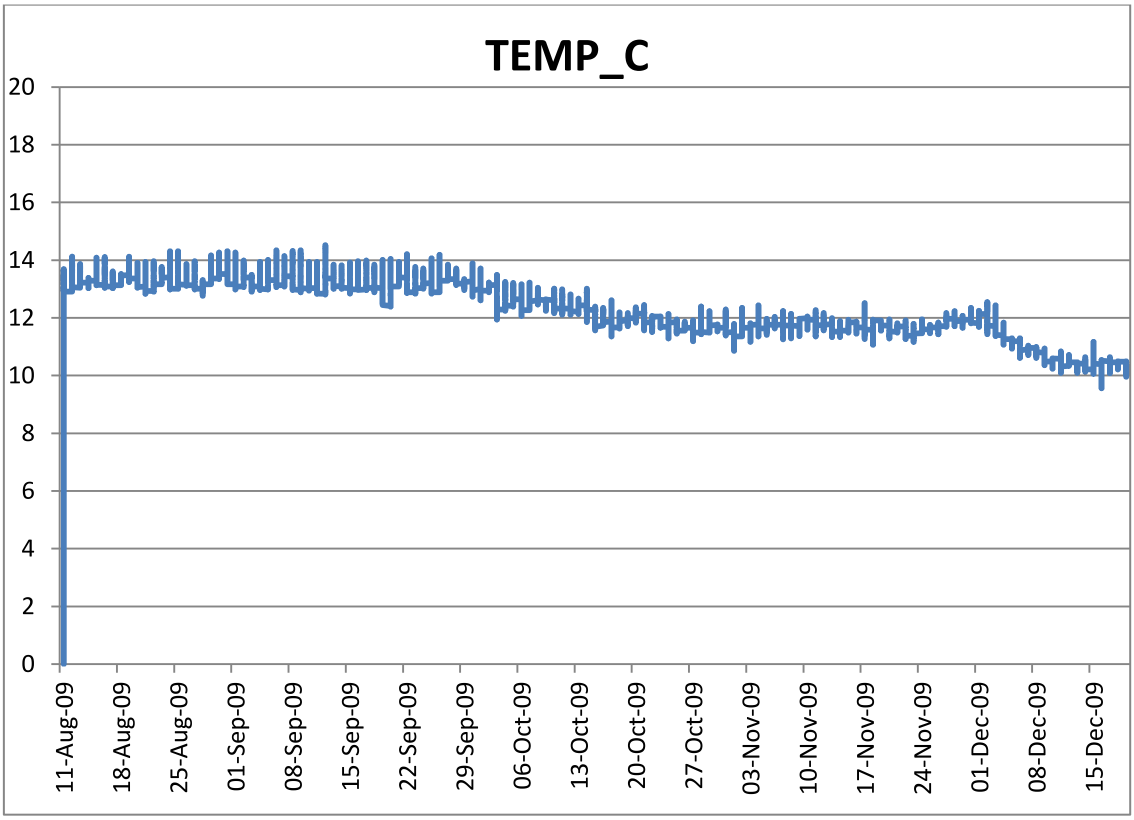


Figure 5.1.6 – SMER Period Temp Variation (Aug to Dec 2009)

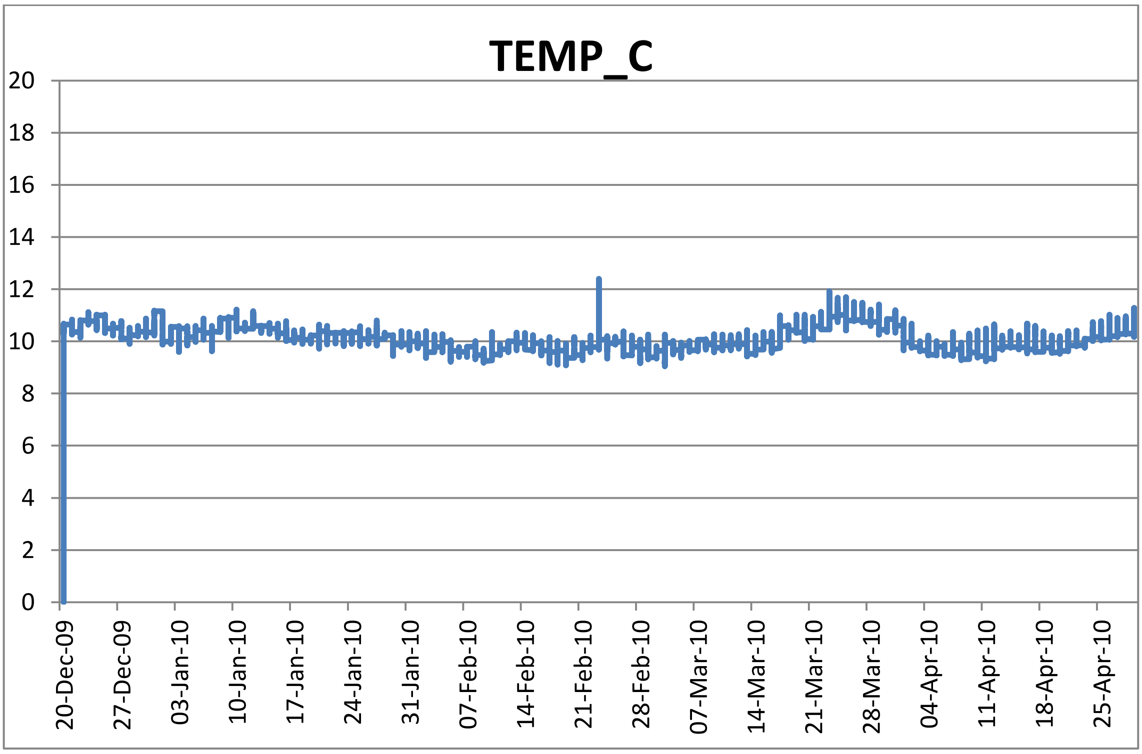


Figure 5.1.7 – SMER Period Temp Variation (Dec 2009 to Apr 2010)

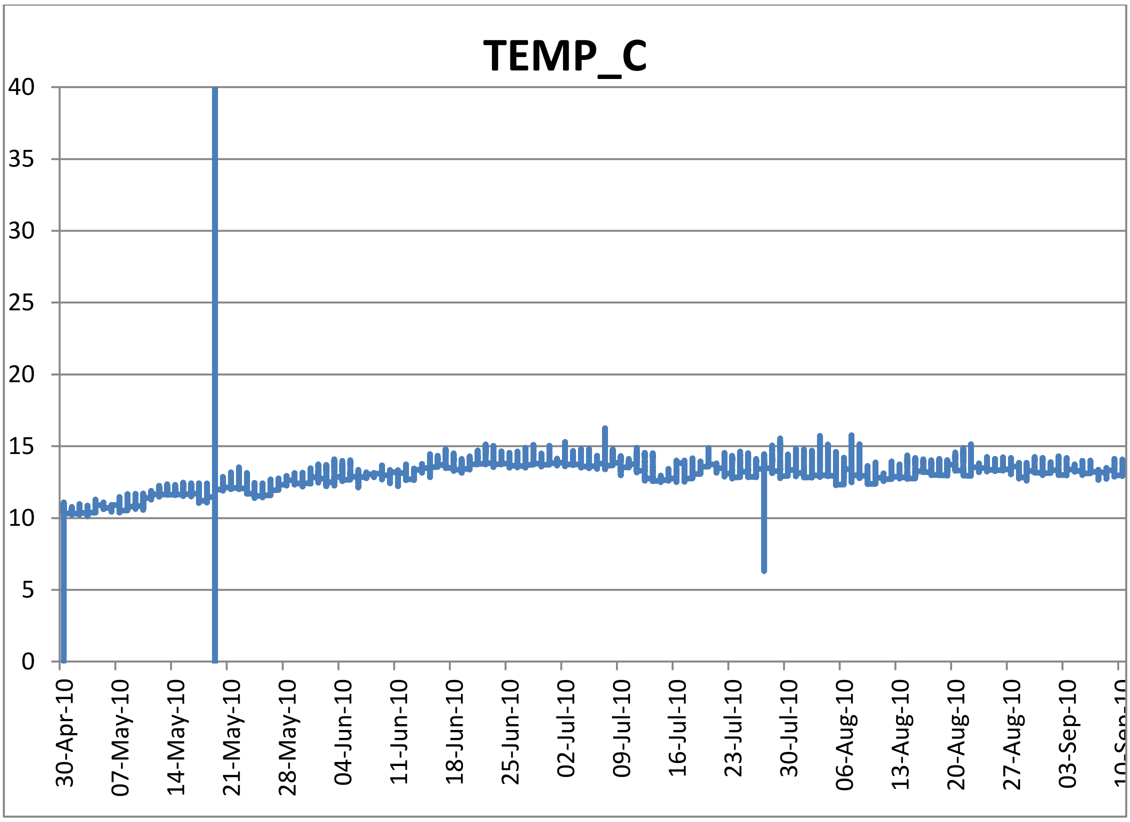


Figure 5.1.8 – SMER Period Temp Variation (Apr to Sep 2010)

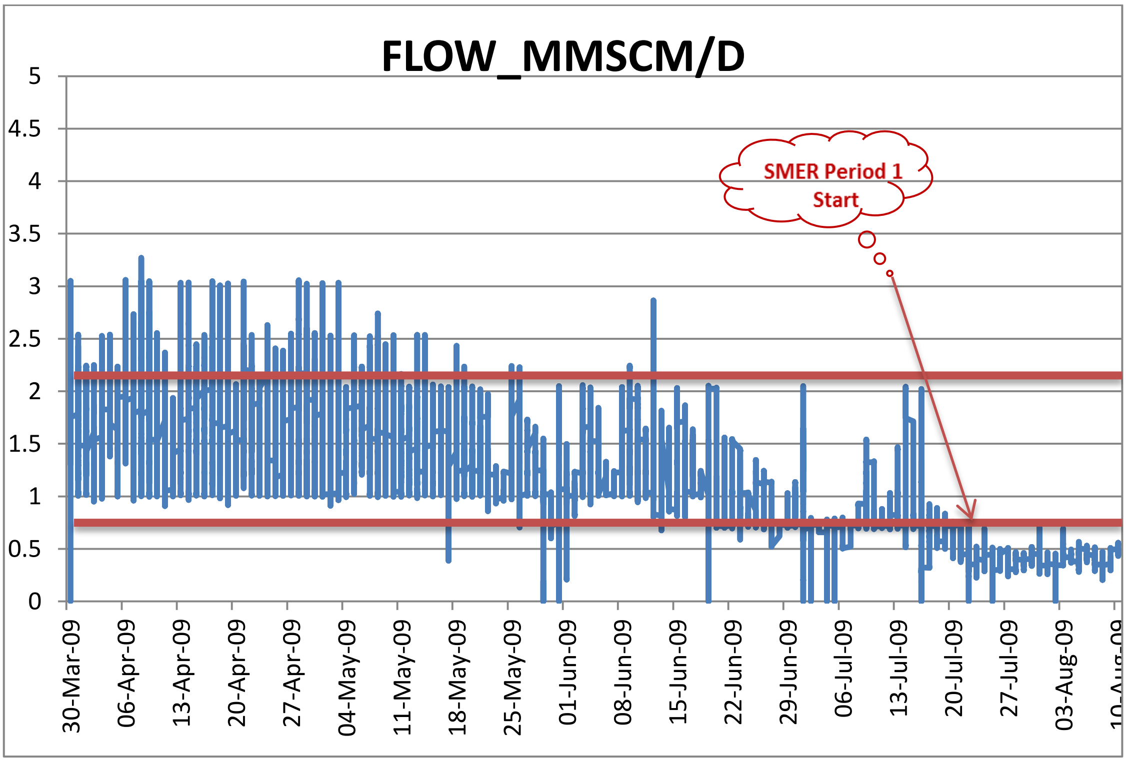


Figure 5.1.9 – SMER Period Flow Variation (Apr to Aug 2009)

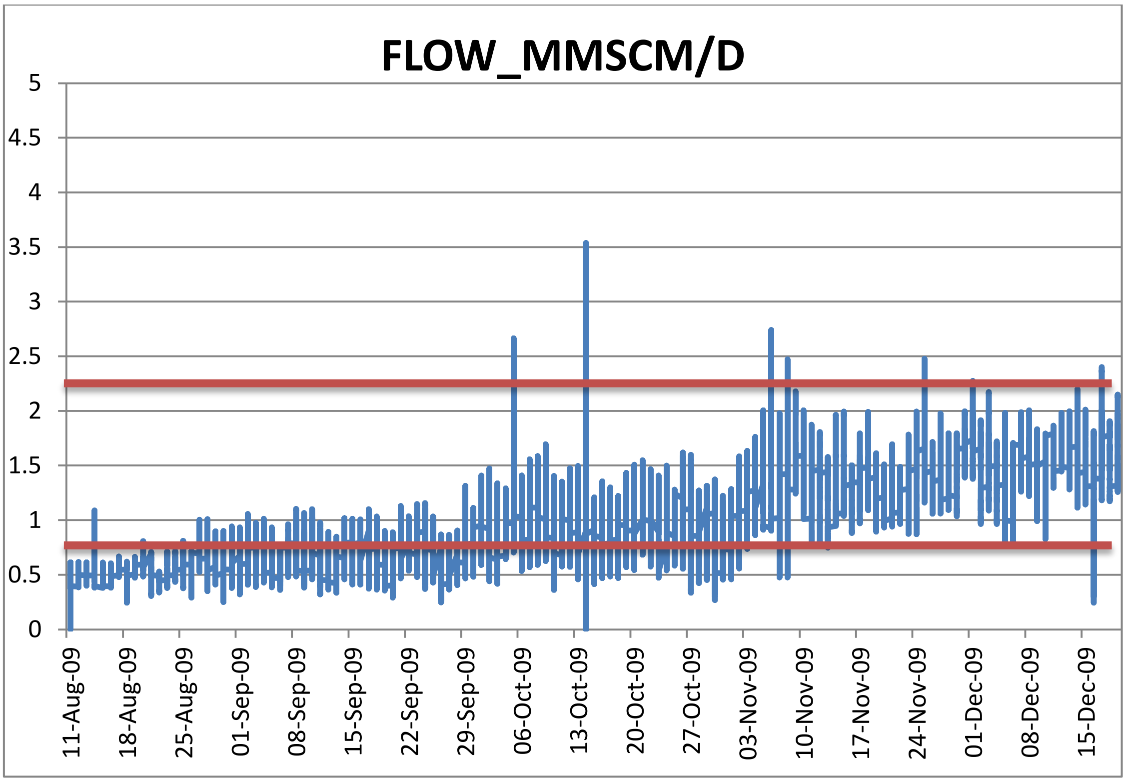


Figure 5.1.10 – SMER Period Flow Variation (Aug to Dec 2009)

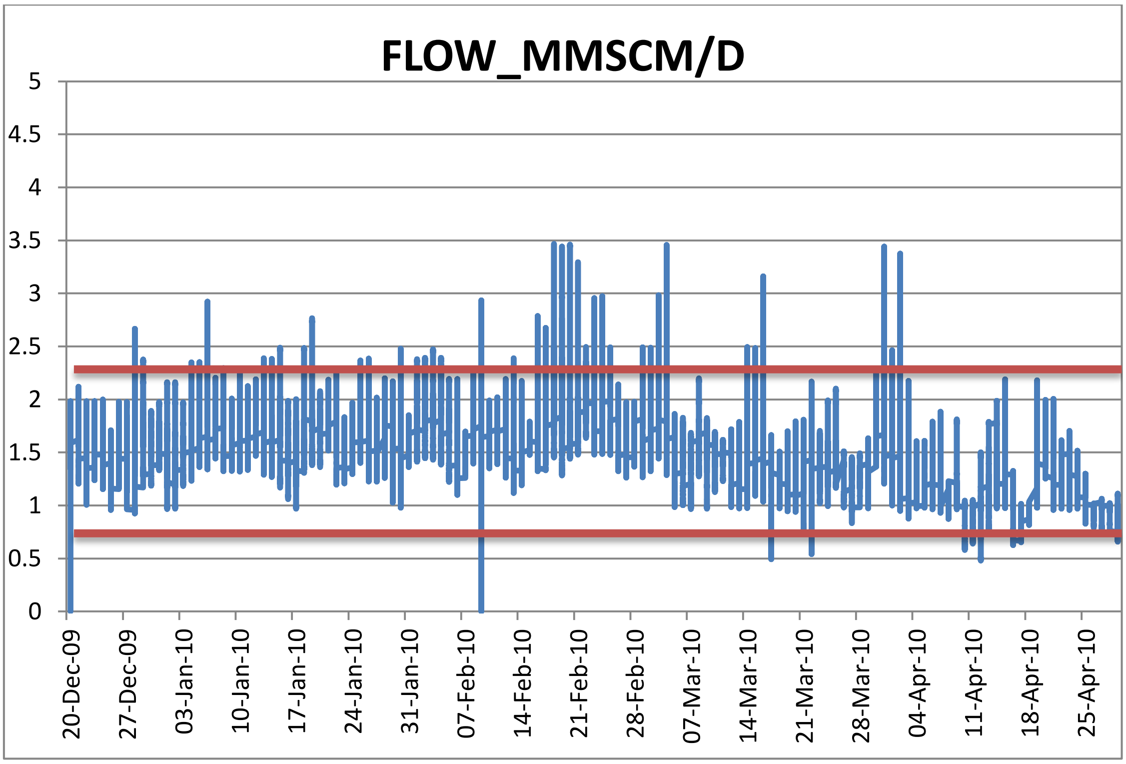


Figure 5.1.11 – SMER Period Flow Variation (Dec 2009 to Apr 2010)

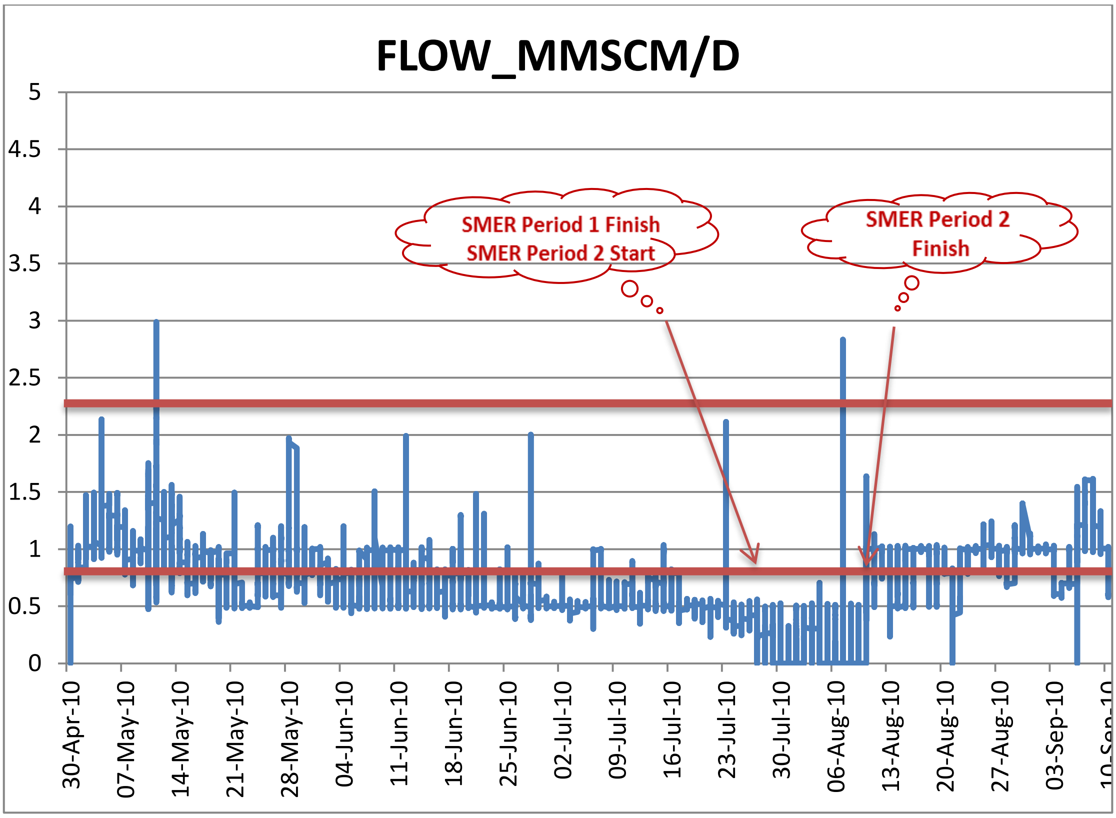


Figure 5.1.12 – SMER Period Flow Variation (Apr to Sep 2010)

From the tabulated data above, the range of operational conditions were established;

- Typical Pressure 58 – 65 BarG
- Typical Flow Rate (during SMER period) 0.25 – 3.5 MMSm^3/day
- Temperature 9 – 14ºC

Using the operating data derived above, a site testing procedure was subsequently prepared (section 5.3 refers).

5.2 Orifice Plate Positional Benchmarking

A site visit was completed on the 30th November 2011 to benchmark the metering installation. A detailed internal inspection of the Orifice Fitting (as it was installed within the pipeline) was completed and catalogued (in photographic & precise dimensional form) with regard the relationship between the Orifice Plate position and the displayed Orifice Carrier Counter. The dimensional data was collected by a representative of FMC (orifice fitting manufacturer) and witnessed by the Appointed Independent Technical Experts – Appendix C refers.

The following counter reading versus orifice plate position was obtained;

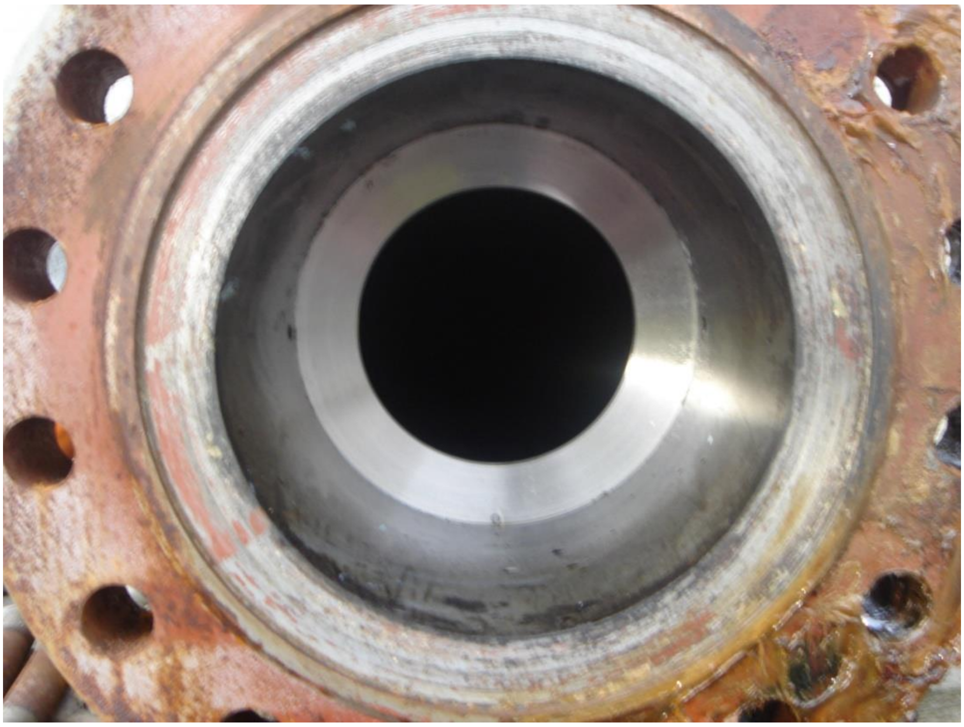


Figure 5.2.1 – Orifice Plate Position (Counter Reading 00000)

Figure 5.2.2 – Orifice Plate Position (Counter Reading 99995)

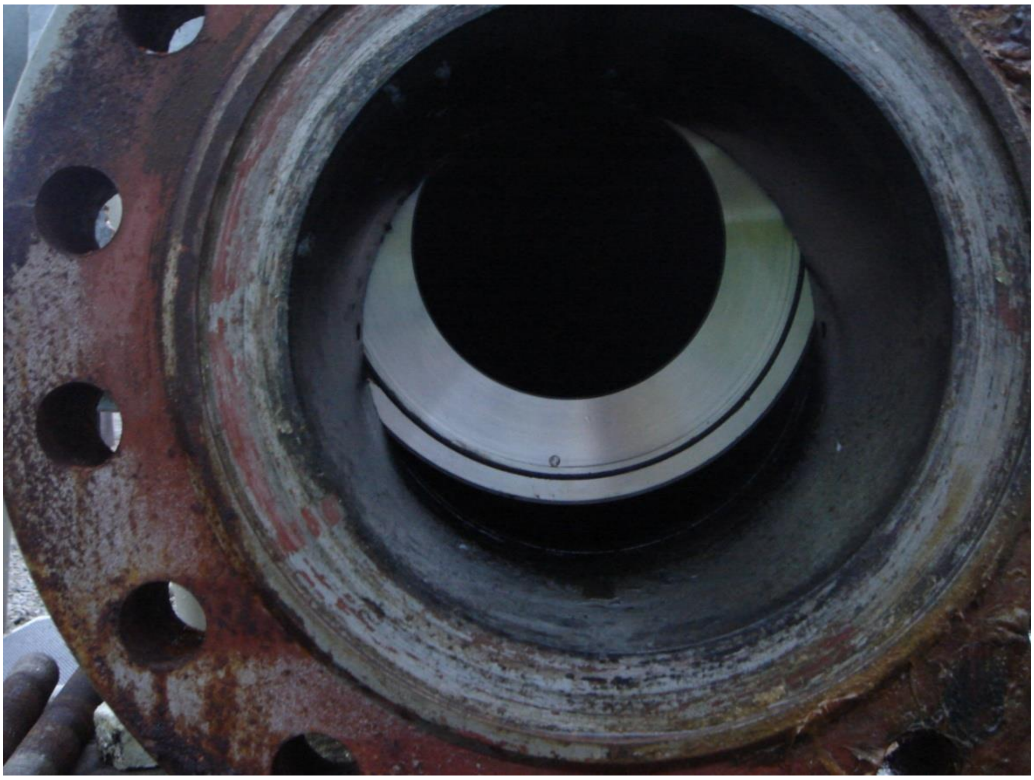


Figure 5.2.3 – Orifice Plate Position (Counter Reading 99985)

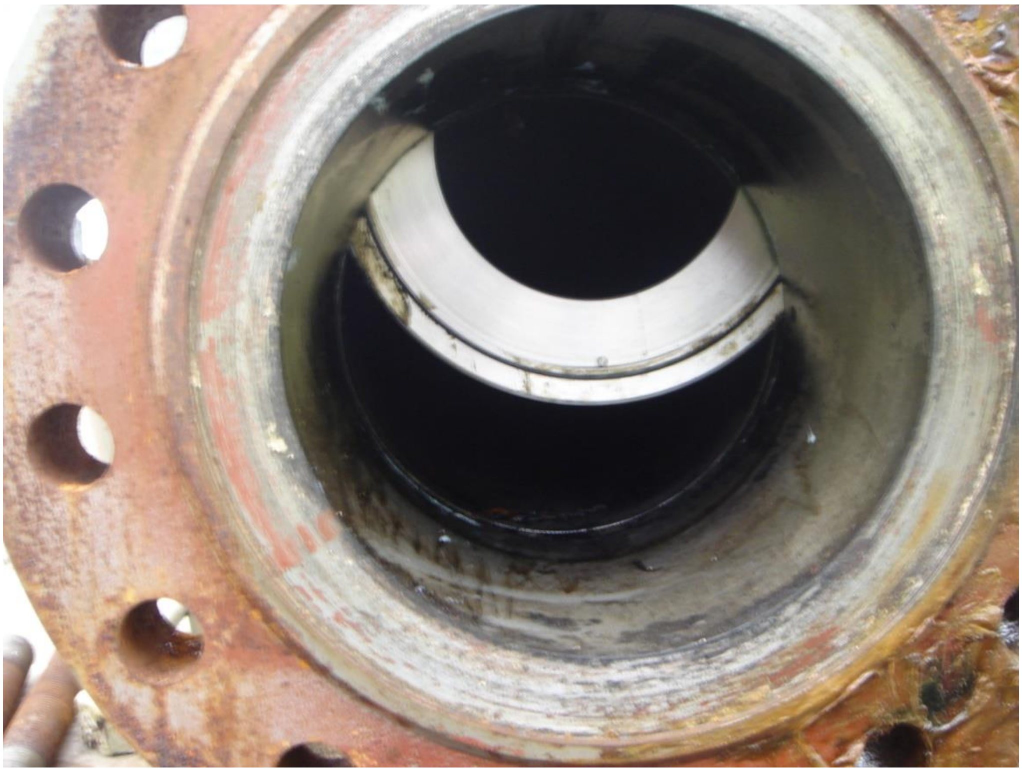


Figure 5.2.4 – Orifice Plate Position (Counter Reading 99970)

Figure 5.2.5 – Orifice Plate Position (Counter Reading 99960)

Figure 5.2.6 – Orifice Plate Position (Counter Reading 99950)

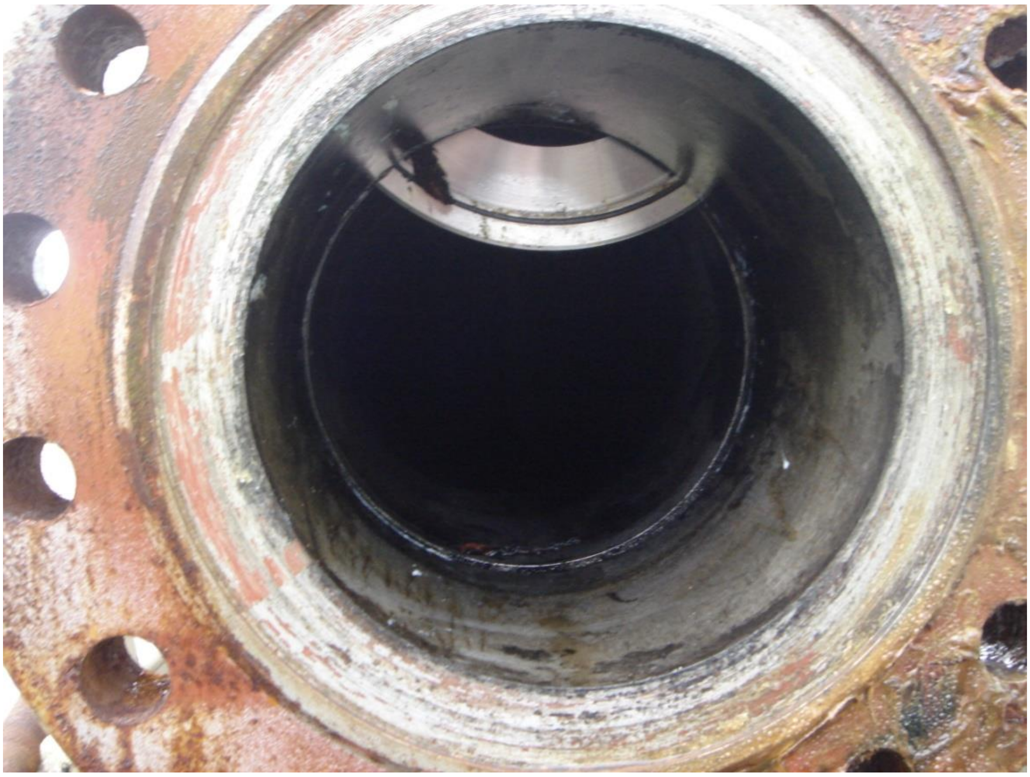


Figure 5.2.6 – Orifice Plate Position (Counter Reading 99940)

From the results of an initial review of the documented counter positions, the following were considered appropriate to use during the site testing (detailed over in section 5.3);

- 00000 (fully "racked-in" position)
- 99985 (one of two potential positions of SMER period #1)
- 99984 (one of two potential positions of SMER period #1)
- 99970 (intermediate position between SMER periods #1 and #2)
- 99950 (potential position of SMER period #2)
- 99885 (fully "racked-out" position)

It was observed during the benchmarking visit that the positioning of the orifice plate varied (with respect to being either to the left or to the right of the centre line) when being "wound-in" and "wound-out" of the fitting.

To ensure any different error results due to this effect were appropriately captured, the above readings were repeated for "winding-in" and "winding-out" operation (see typical results graph – Figure 5.3).

5.3 Site Test Procedure

A site test procedure was developed as follows;

- Site testing to be performed at typically minimum, medium and maximum flow rates seen during the SMER period (starting flow rates established to account for range in error flows). ***These flow bands are incorporated within graphs 5.1.9 to 5.1.12 for visual reference;***

    - 1 MMSm^3/day (error flow rate down to 0.25)
    - 3 MMSm^3/day (error flow rates between 0.8 to 2.2)
    - 4.5 MMSm^3/day (error flow rate up to 3.5)

- Site testing to be performed with a range of inlet pressures that can be deemed representative of the operating pressures seen during the SMER period.

    - 58 BarG
    - 61.5 BarG
    - 65 BarG

- Provision to provide a "tabulated" record in "real time" (10 second continuous update) the outputs of the following measured variables to be made available;

    - Low ΔP
    - High (Duty) ΔP
    - High (Standby) ΔP
    - Pressure
    - Instantaneous Standard Volume Flow

  Note: The following outputs to be manually recorded from the OMNI flow computer;

    - Temperature
    - Density

- For each of the flow scenarios, the configuration of the flow metering stream shall be replicated (i.e. for each orifice plate position required).

- Once a flow scenario has been replicated and established, the following actions shall be implemented;

    - Ensure all measured variables are recording satisfactorily and ensure a "date and time stamp" of some description is incorporated.

    - Align orifice plate position (in counter readings of 00000 [fully racked in], 99985, 99984, 99970, 99950, 99885 [fully racked out], 99950, 99970, 99984, 99985 and 000000 [fully racked in]).

    - Ensure that there is sufficient time (between each orifice plate positional change) for flow rate stabilisation.

- Repeat the above for all selected flow and pressure scenarios (minimum of 9 tests);

- Collate all records on completion of testing.

- For each site test, calculate the difference in flow rate for each orifice plate position as follows;

    - Calculate the reference standard volume flow rate value (i.e. that with a fully "racked in" orifice plate at counter reading 00000) by taking the average of each recorded start and finish test flow rate. Note the flow rate stability during the test……………………………………………………….(1)

    - Calculate the average standard volume flow rate that represents each of the orifice plate positions, from the OMNI flow computer flow rate output (10 second data) for the duration of each test…………………………………………………………………………………….(2)

    - For each orifice plate position, calculate the % difference between (1) and (2) above.

  Note: Following completion and post review of the site test data, some refinements were required to adjust the methodology above (section 5.4 refers).

  A typically set of graphed results for one test run can be seen in Figure 5.3 over.

- Collate results in graphical & tabular form to include within report section 6.0.

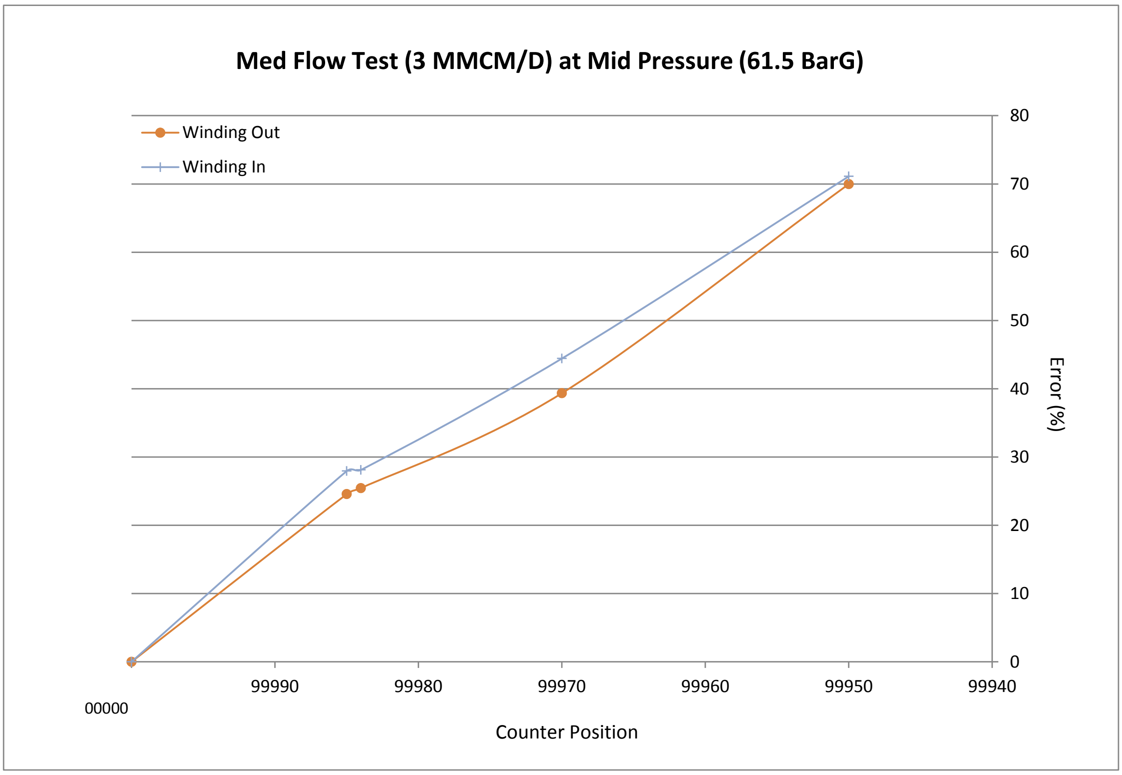


Figure 5.3 – Typical Results Graph

5.4 Post Site Testing Refinements

Due to the relevant instability of the site testing (see individual site test results within Section 6.0), the following methodology for the calculation of flow test error was applied;

- Error #1 – Calculated using the average of all 4-minute rbd data recorded during the "stabilisation flow period" **prior** to the test commencement of each individual test.

- Error #2 – Calculated using the average of all 4-minute rbd data recorded during the "stabilisation flow period" **following** test completion of each individual test.

- Error #3 – Calculated using the average of the stabilisation flow period prior to and commencement of, each individual test.

- Actual Error – As it cannot be confirmed at which stage the instability occurred or the rate at which it diminished or increased throughout the test durations the actual error has been estimated from the average of the sum of errors #1, #2 and #3 for each individual test.

6.0 SITE TEST RESULTS

6.1 Site Testing Introduction

The site testing procedure (Section 5.3 refers) was completed on two separate site visits;

Visit 1 – 15th February 2012

Completed tests;

Test 1 – Low Flow (≈1.0 MMSm^3/day) / Mid Pressure (≈61 BarG)
Test 2 – Med Flow (≈3.0 MMSm^3/day) / Mid Pressure (≈61 BarG)
Test 3 – High Flow (≈4.5 MMSm^3/day) / Mid Pressure (≈61 BarG)

Visit 2 – 18th to 19th April 2012

Completed tests (18th April);

Test 4 – Med Flow (≈3.0 MMSm^3/day) / High Pressure (≈64 BarG)
Test 5 – Aborted due to operation of low pressure override during testing.
Test 6 – Low Flow (≈1.0 MMSm^3/day) / High Pressure (≈64 BarG)
Test 7 – High Flow (≈4.5 MMSm^3/day) / High Pressure (≈64 BarG)

Completed tests (19th April);

Test 8 – Med Flow (≈3.0 MMSm^3/day) / Low Pressure (≈58 BarG)
Test 9 – Low Flow (≈1.0 MMSm^3/day) / Low Pressure (≈58 BarG)
Test 10 – High Flow (≈4.5 MMSm^3/day) / Low Pressure (≈58 BarG)
Test 11***** – Repeat of Test 9; Low Flow (≈1.0 MMSm^3/day) / Low Pressure (≈58 BarG)

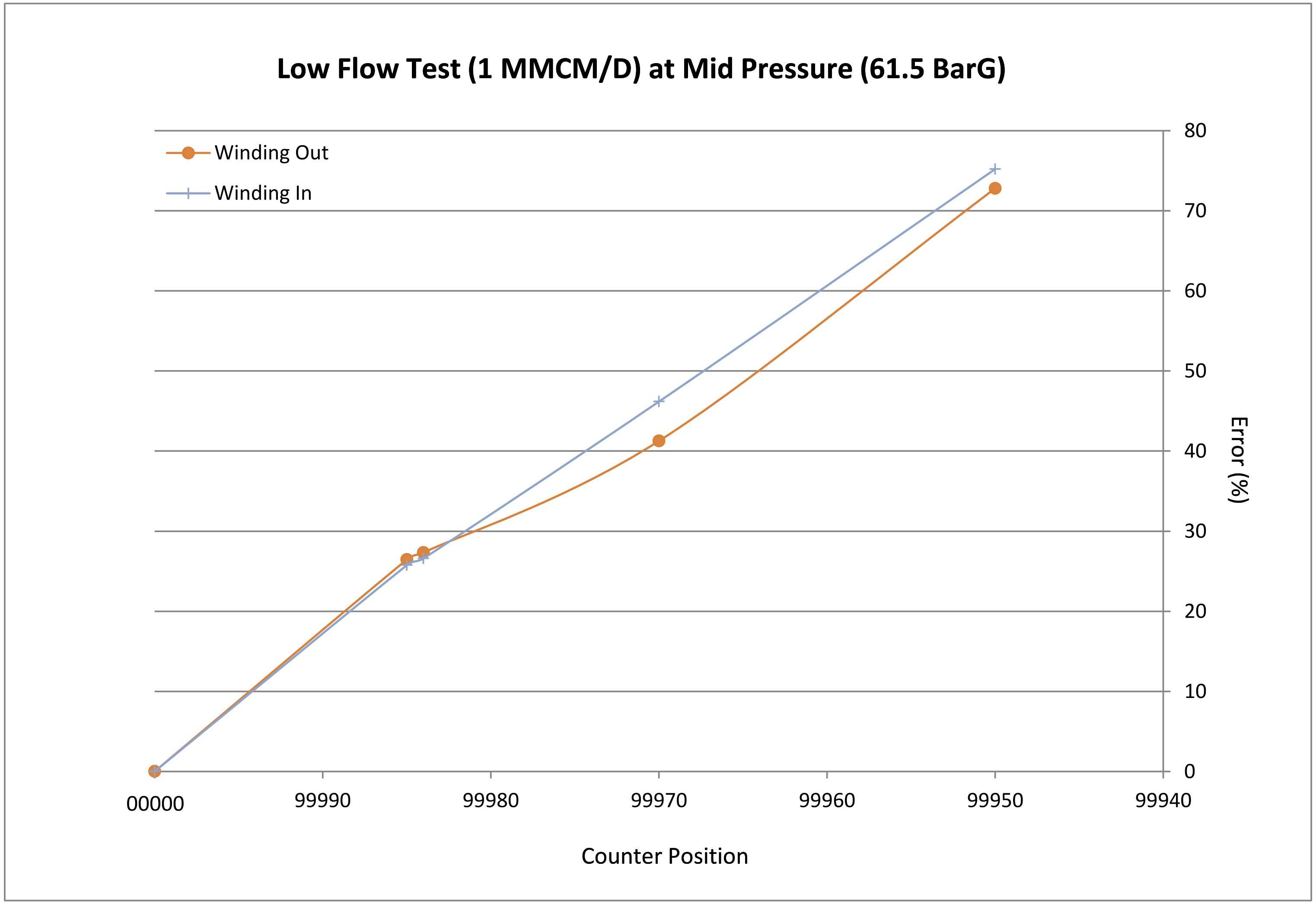
(*) Due to an uncharacteristic shift seen during Test 9 at the SMER period 2 counter reading of 99950 (in relation to all other tests) a repeat test (Test 11) was completed which supported the first set of results in Test 9. However, the CFD results for these test points (section 8 refers) record a significant discrepancy which potentially casts doubt over the acceptability of these site test values.

The CFD results for Test 1 (99950) also records a significant discrepancy which again potentially casts doubt over the acceptability of this site test value (section 8 again refers).

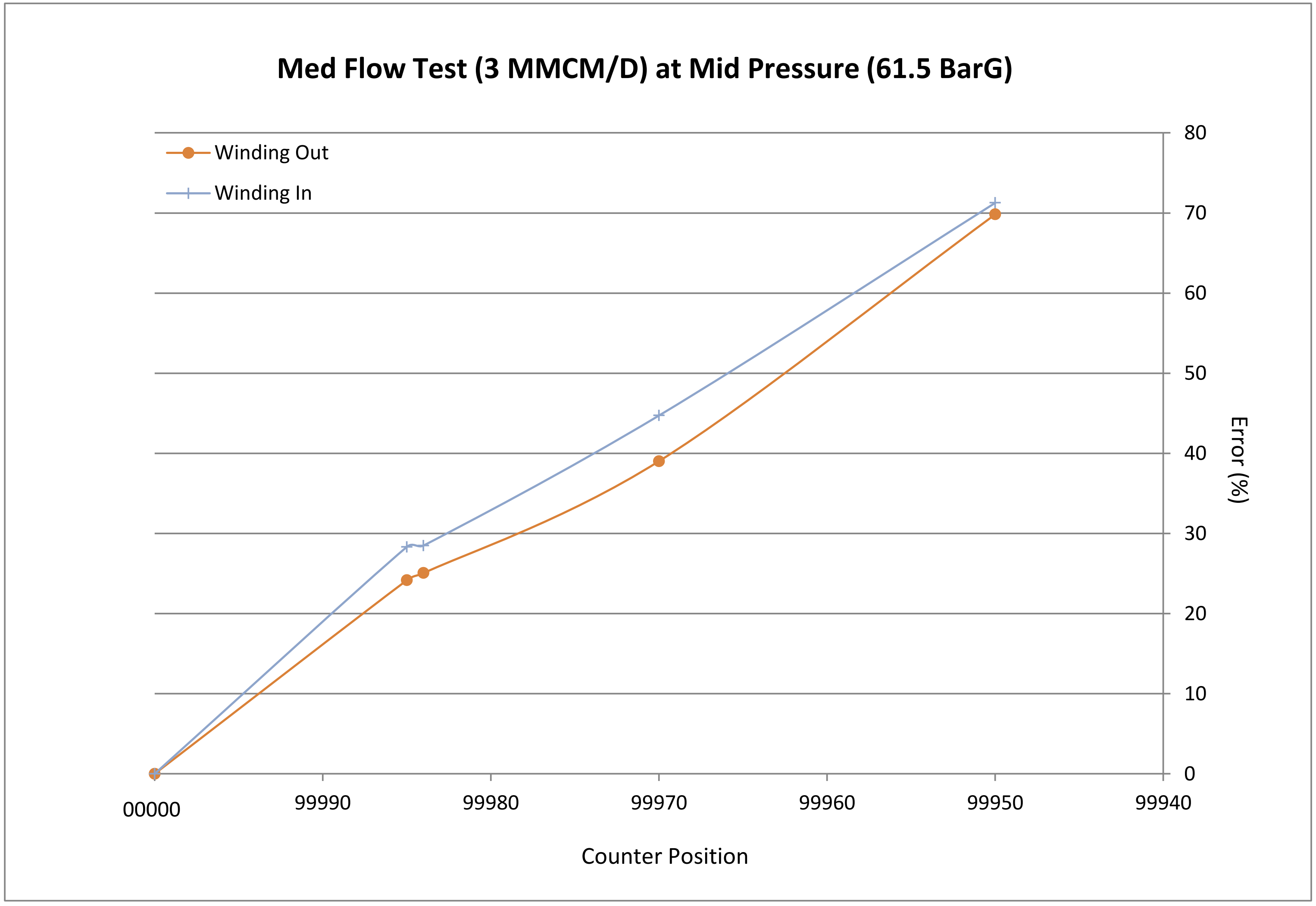
All other test results followed a very similar trend at all counter readings although it was disappointing that the flow stability during some of the tests was not as good as others.

The results for all site tests referenced above are detailed in graphical presentations and included within this report section accordingly.

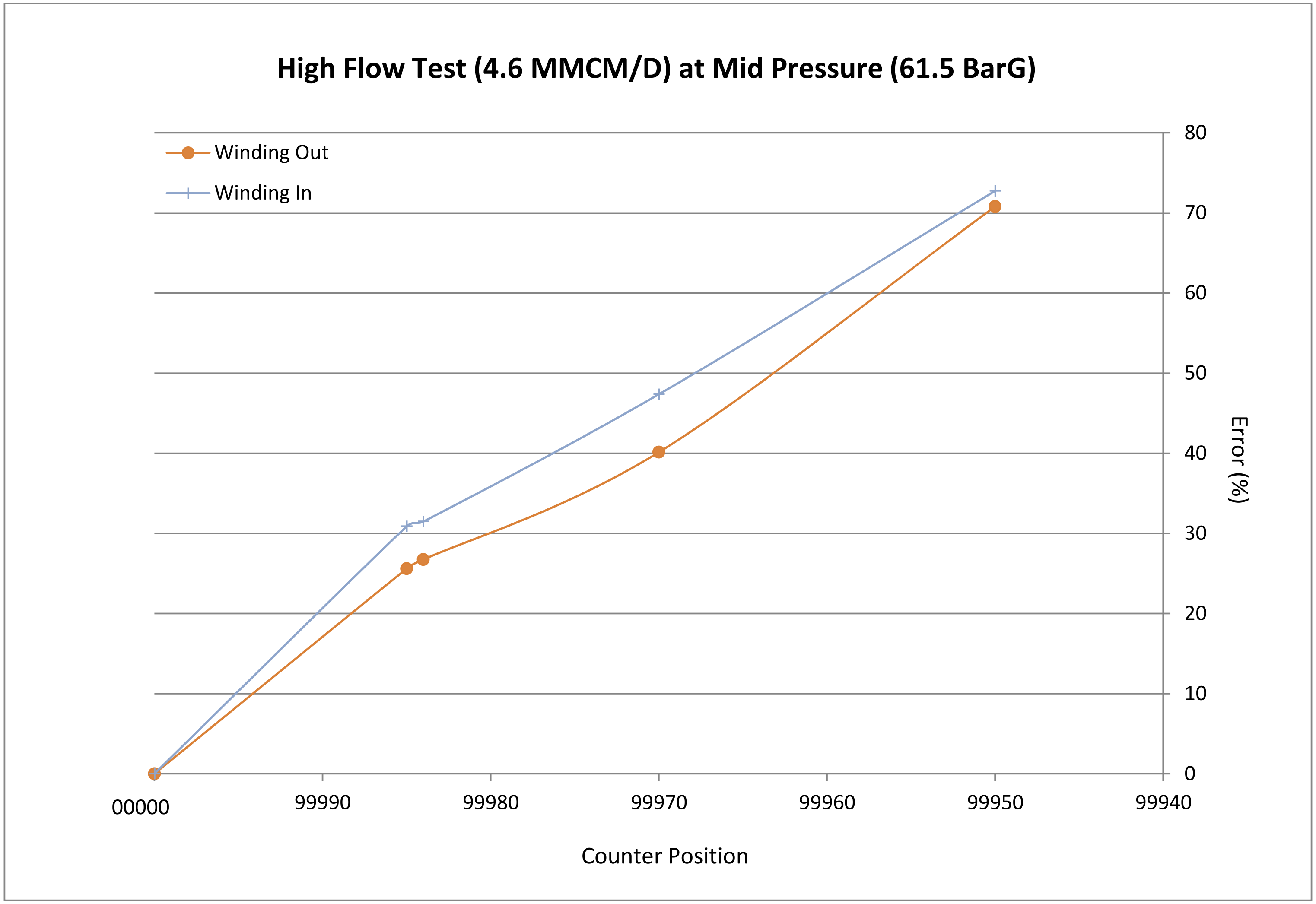
6.2 - Test 1


Low Flow Test (1 MMCM/D) at Mid Pressure (61.5 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

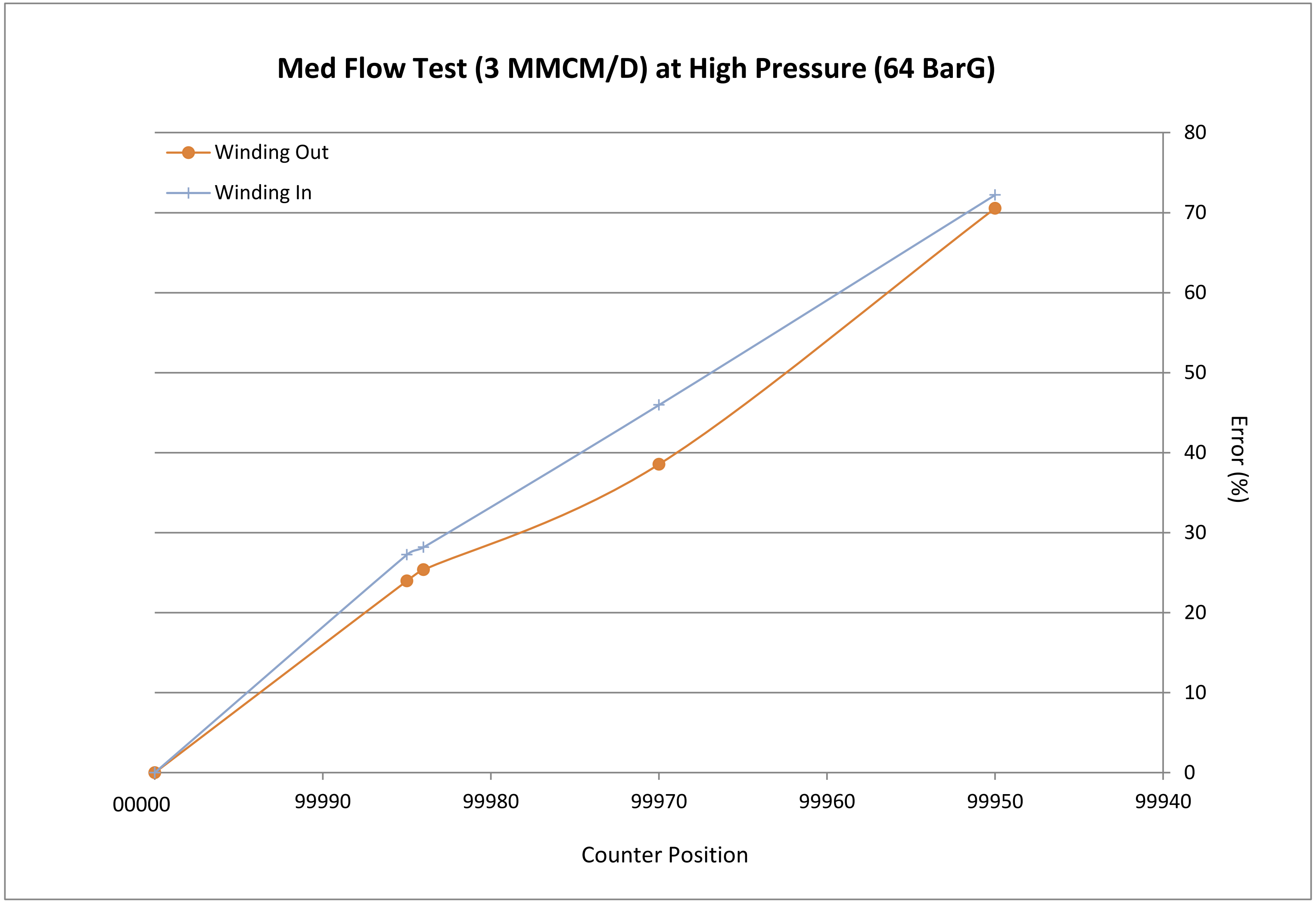
6.3 - Test 2


Med Flow Test (3 MMCM/D) at Mid Pressure (61.5 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

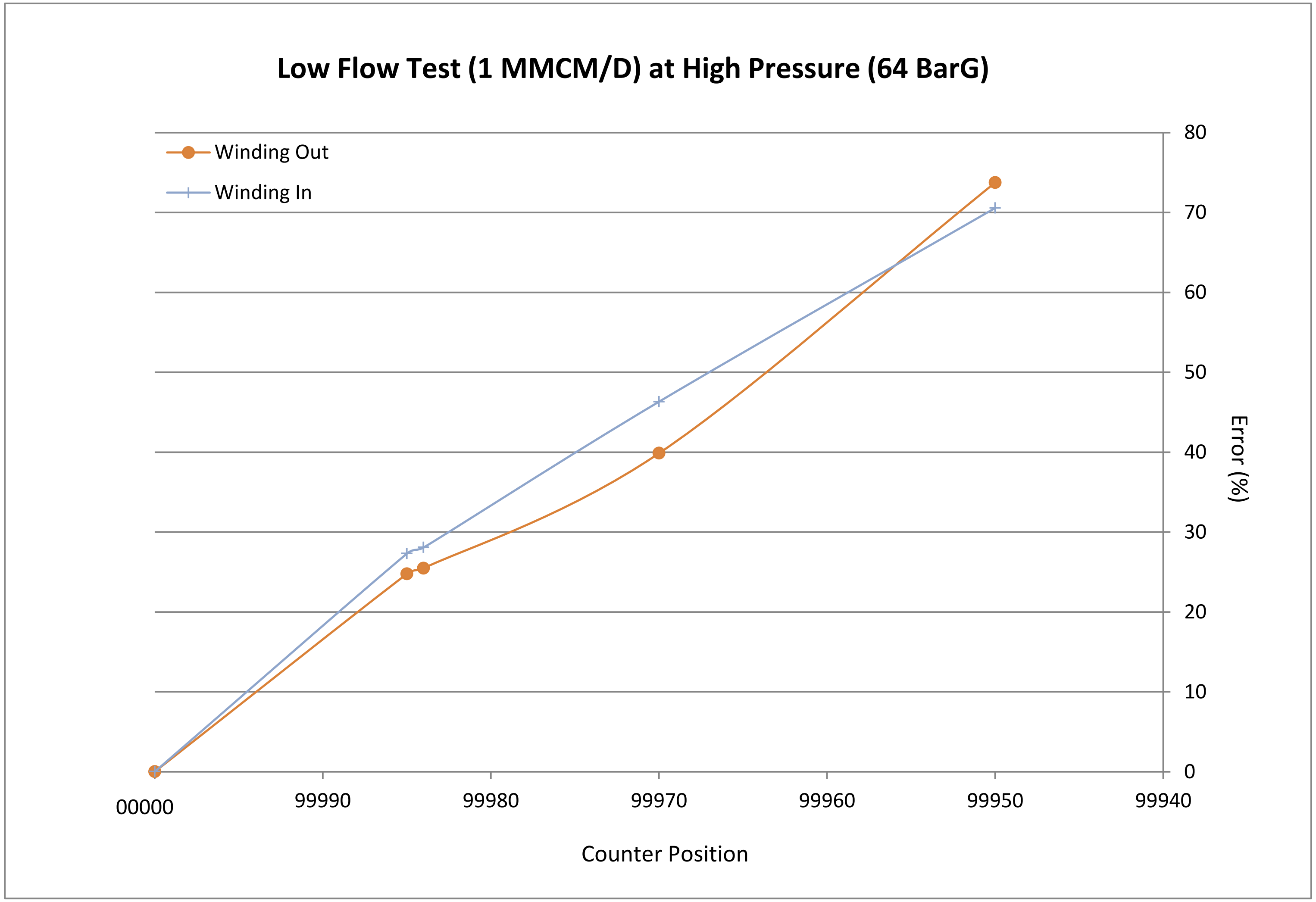
6.4 - Test 3


High Flow Test (4.6 MMCM/D) at Mid Pressure (61.5 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

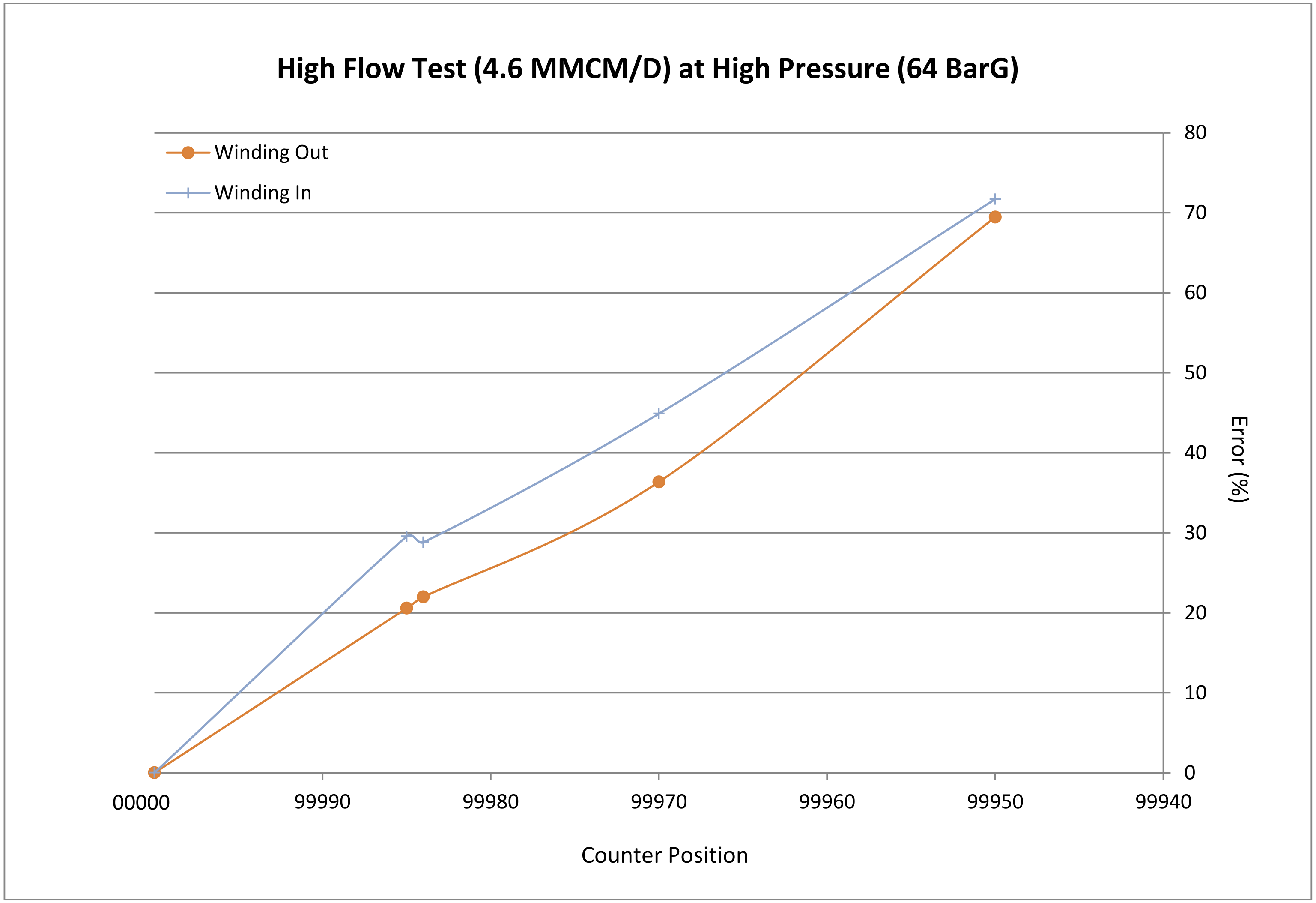
6.5 - Test 4


Med Flow Test (3 MMCM/D) at High Pressure (64 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

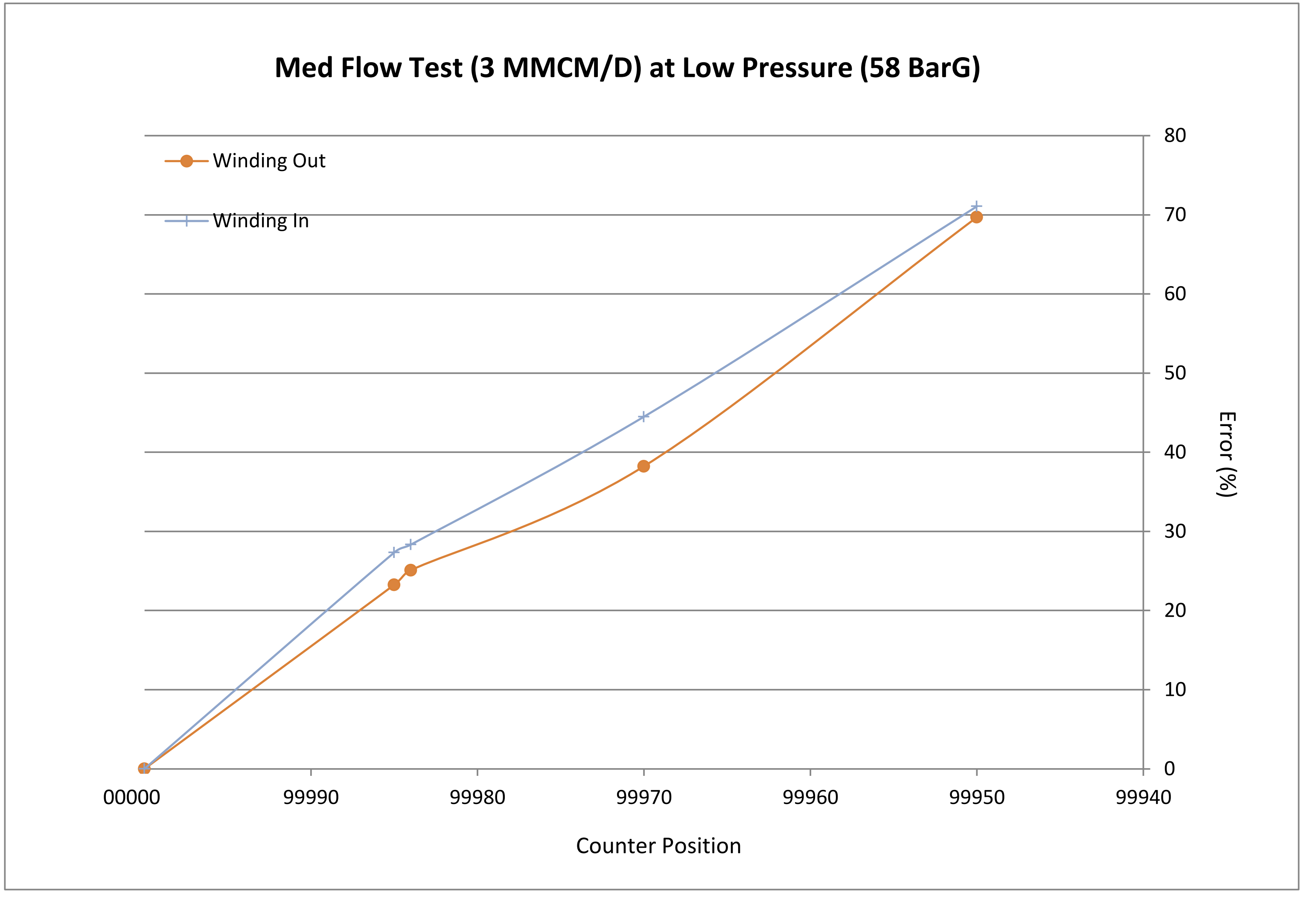
6.6 - Test 6


Low Flow Test (1 MMCM/D) at High Pressure (64 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

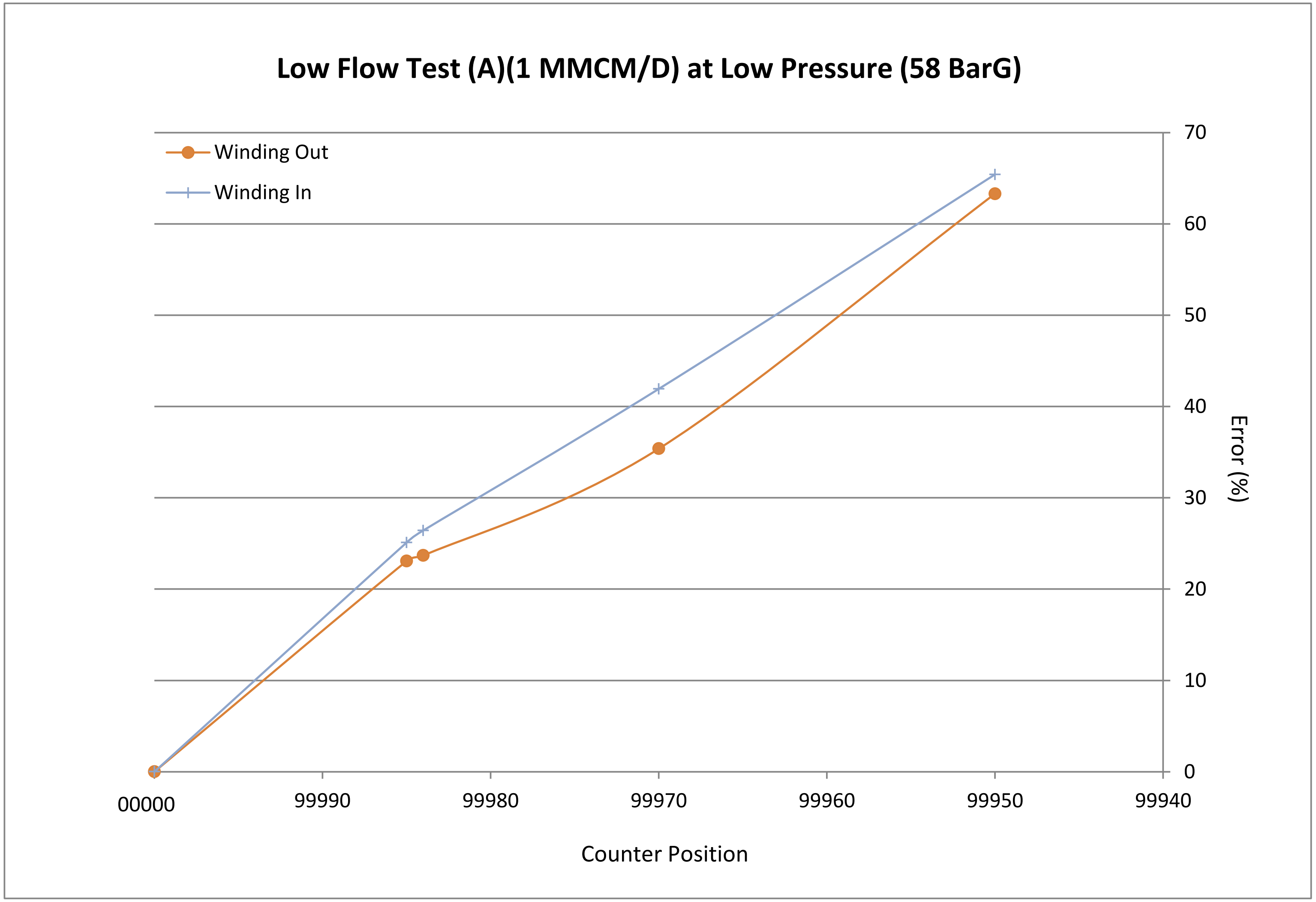
6.7 - Test 7


High Flow Test (4.6 MMCM/D) at High Pressure (64 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

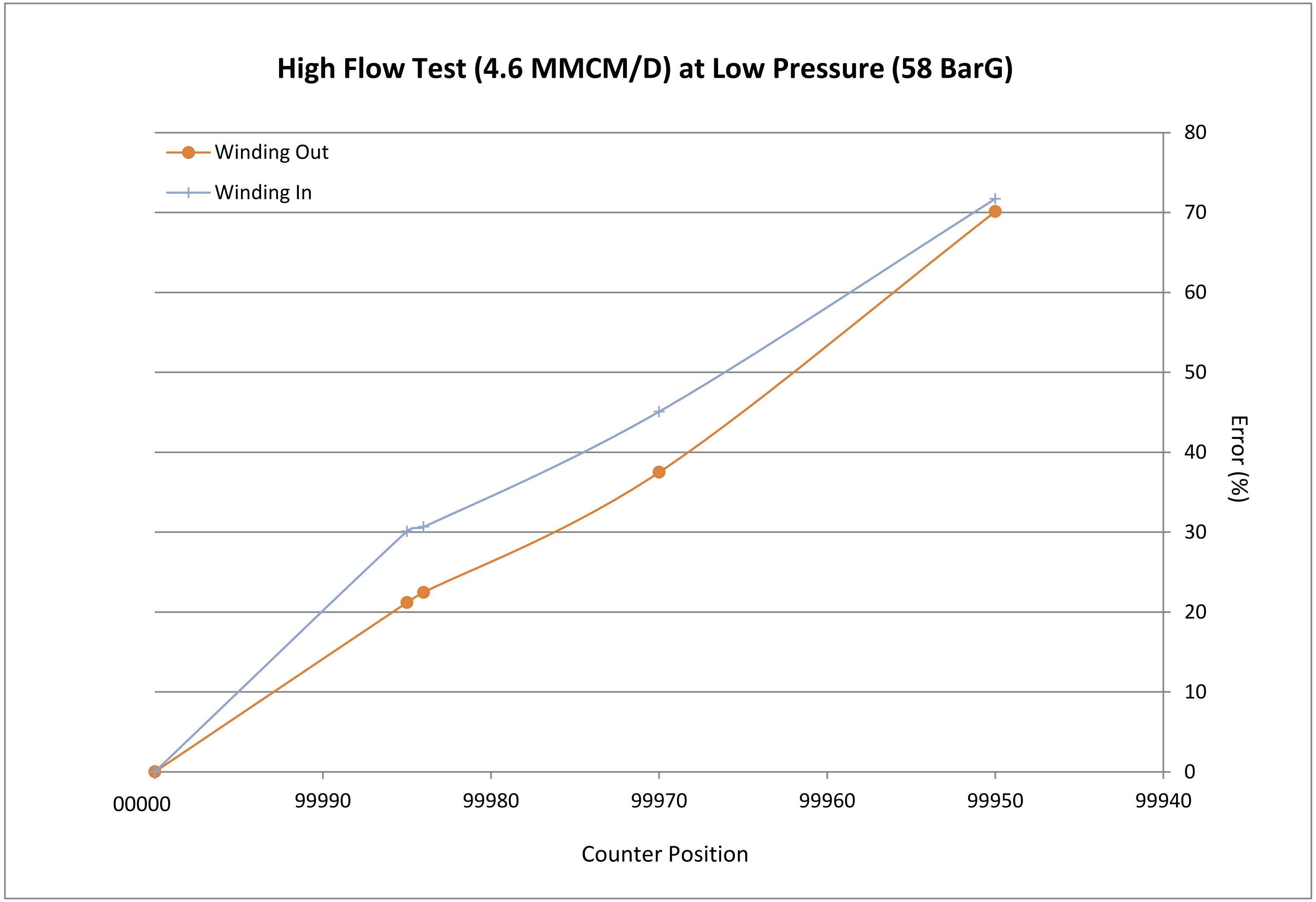
6.8 - Test 8


Med Flow Test (3 MMCM/D) at Low Pressure (58 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

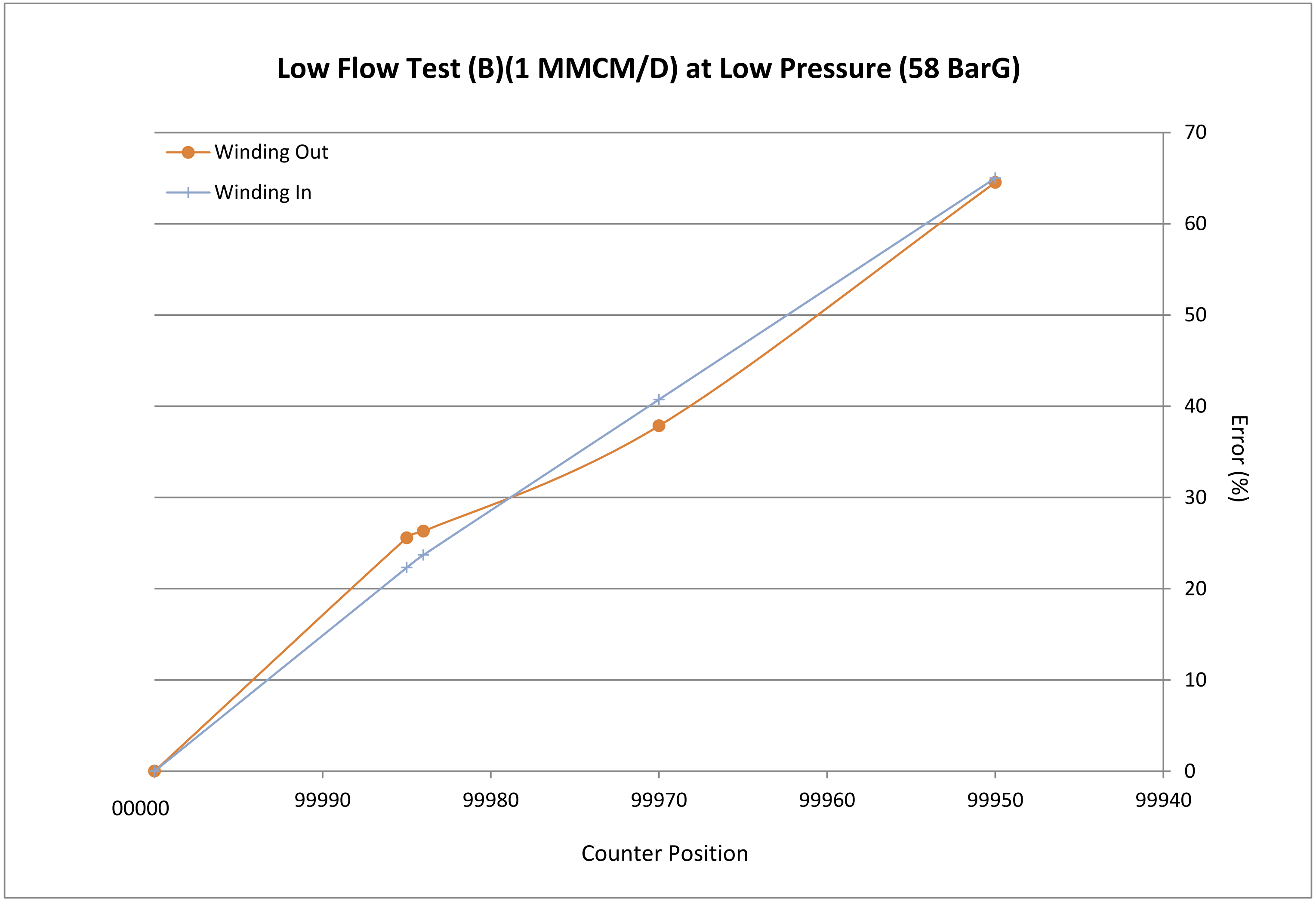
6.9 - Test 9


Low Flow Test (A)(1 MMCM/D) at Low Pressure (58 BarG)
Winding Out
Winding In
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

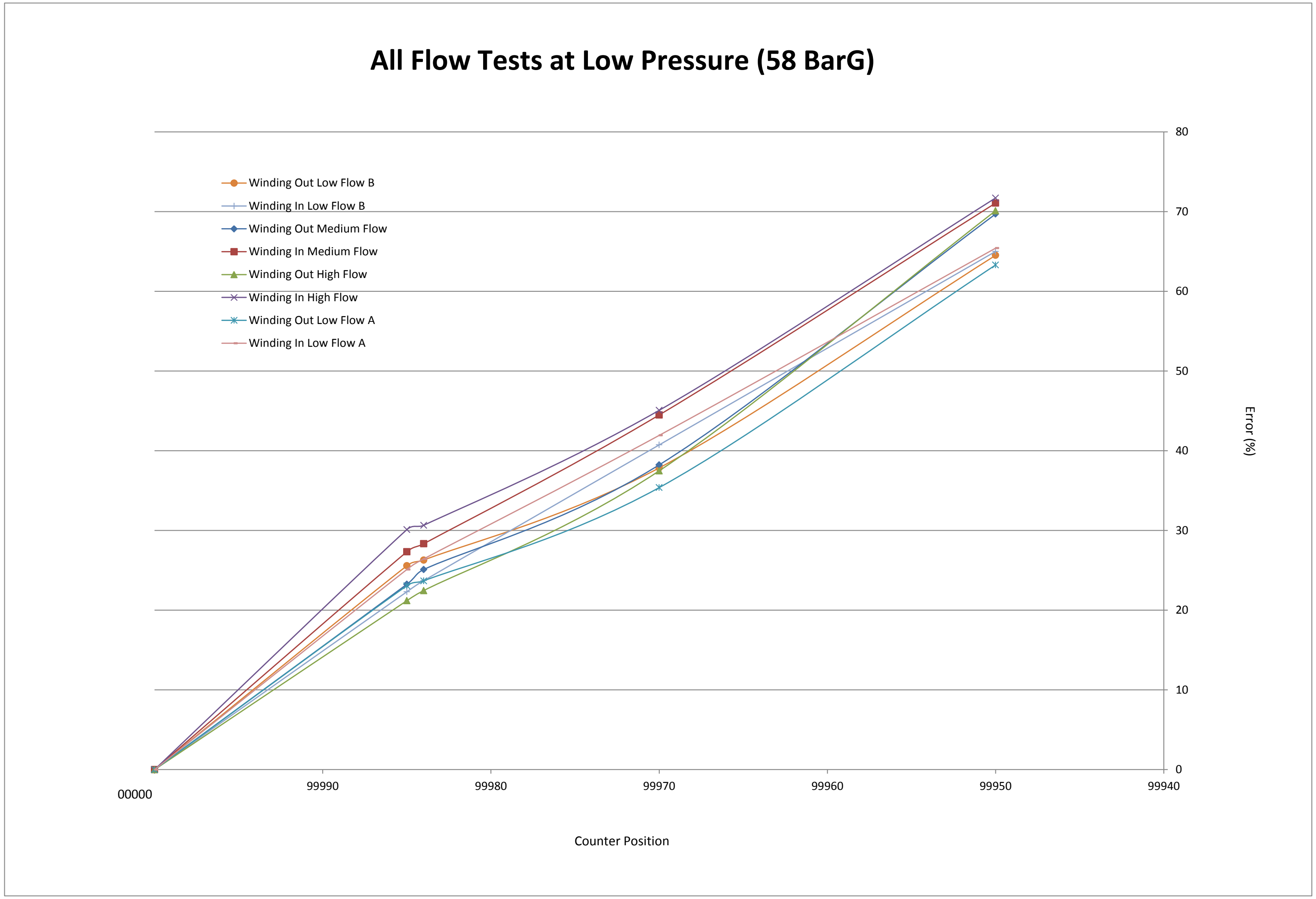
6.10 - Test 10


High Flow Test (4.6 MMCM/D) at Low Pressure (58 BarG)
Winding Out
Winding In
80
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

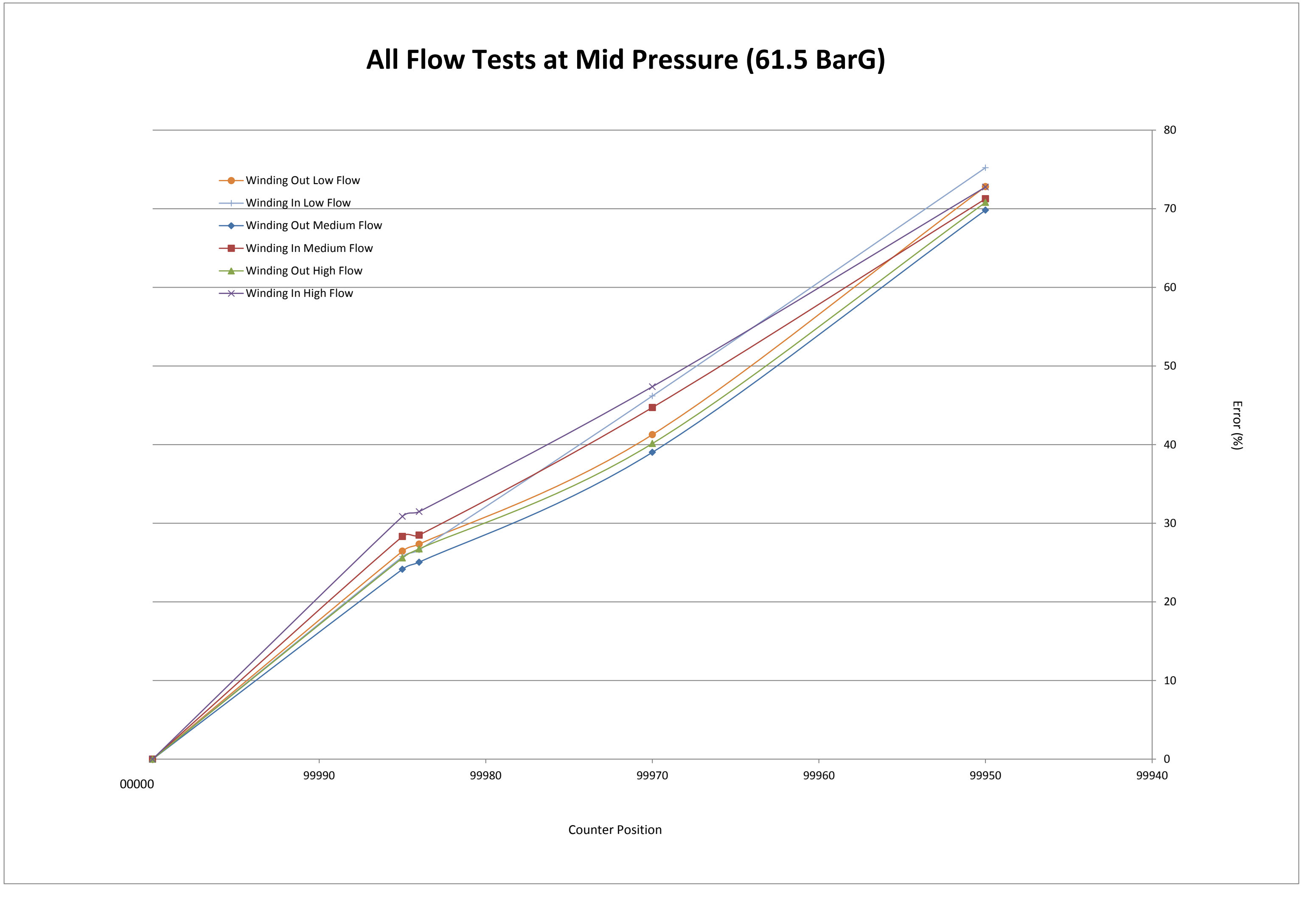
6.11 - Test 11


Low Flow Test (B)(1 MMCM/D) at Low Pressure (58 BarG)
Winding Out
Winding In
70
60
50
40
30
20
10
0
Error (%)
00000
99990
99980
99970
99960
99950
99940
Counter Position

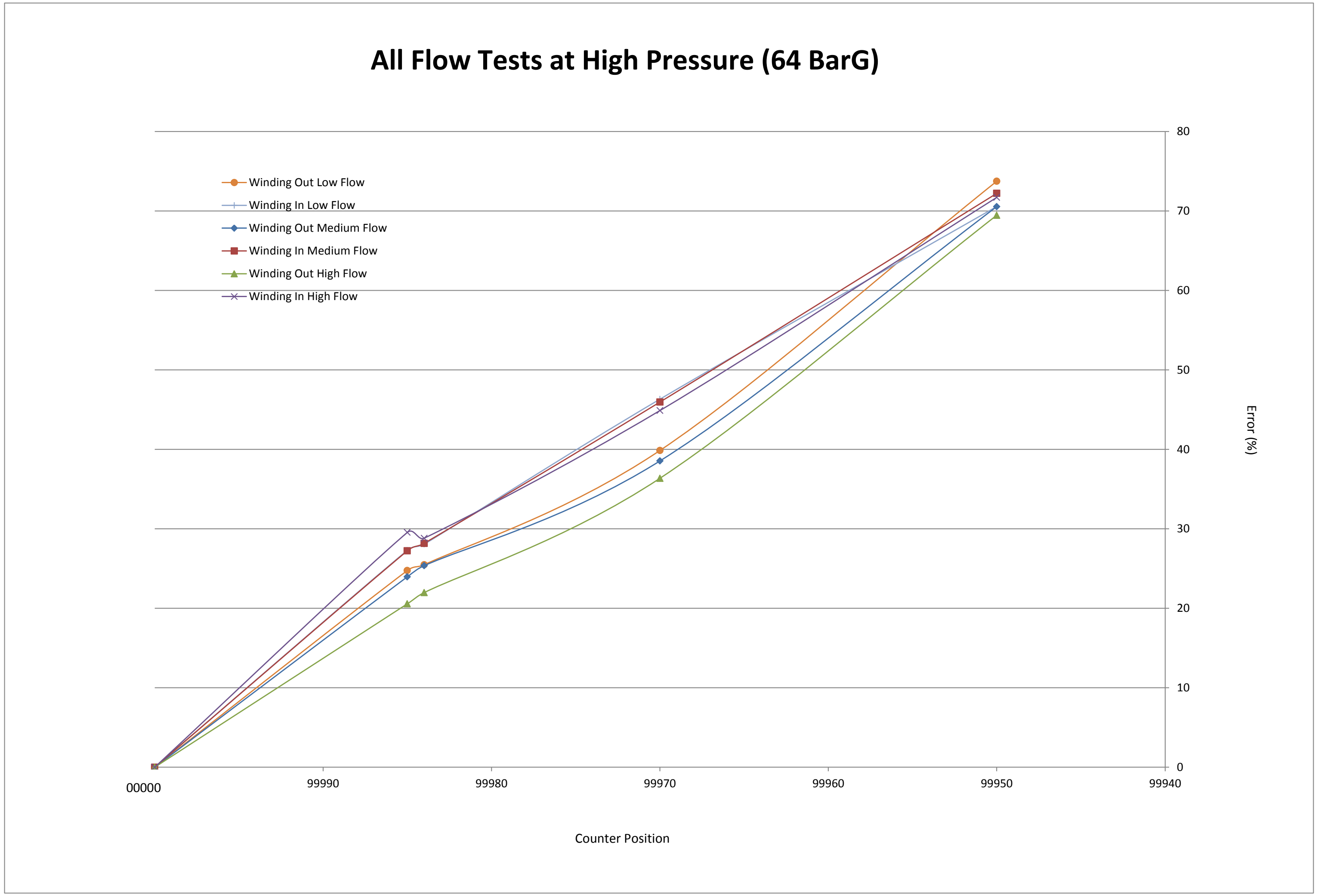
6.12 – All Tests (Low Pressure)



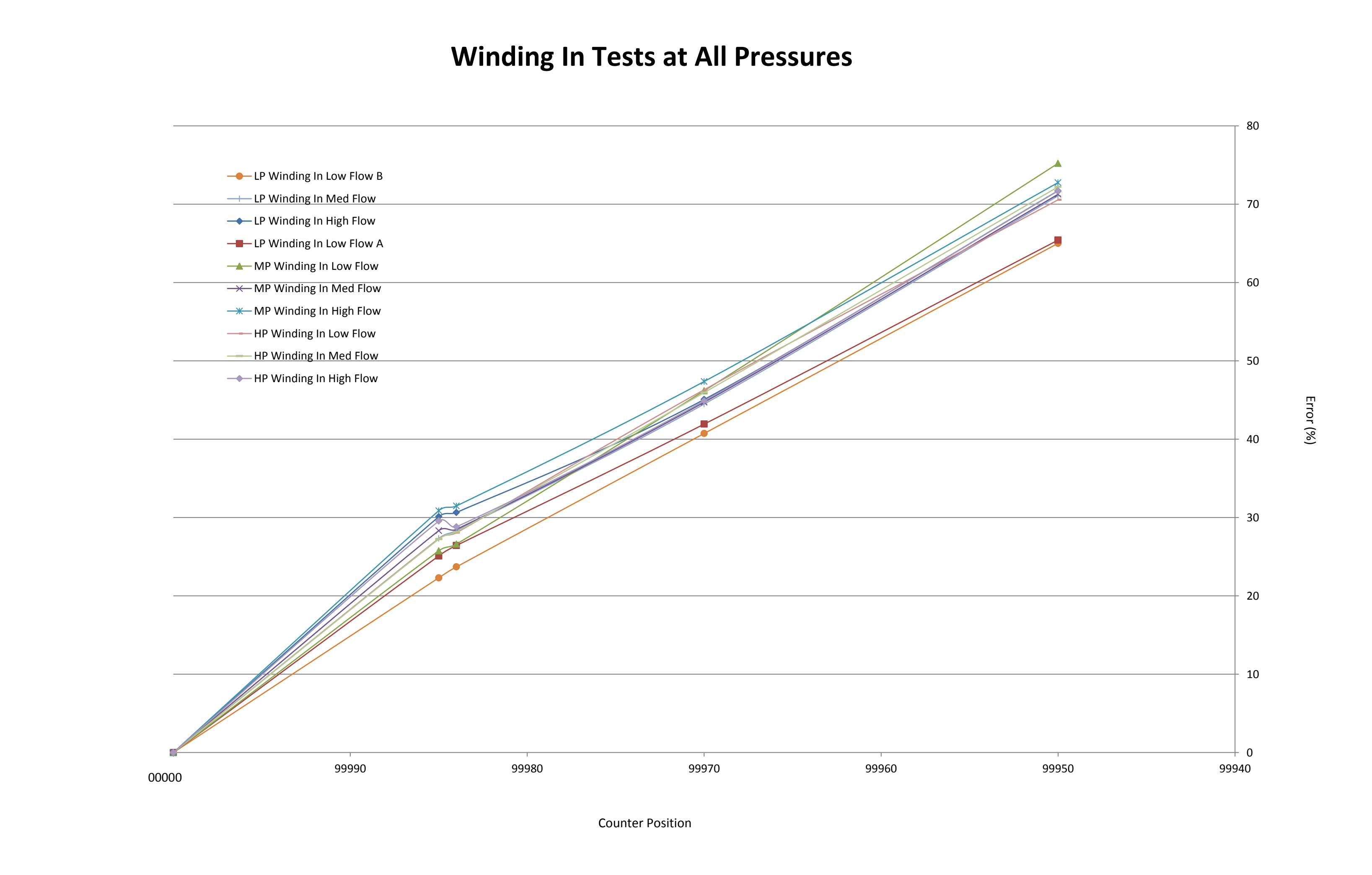
6.13 – All Tests (Mid Pressure)



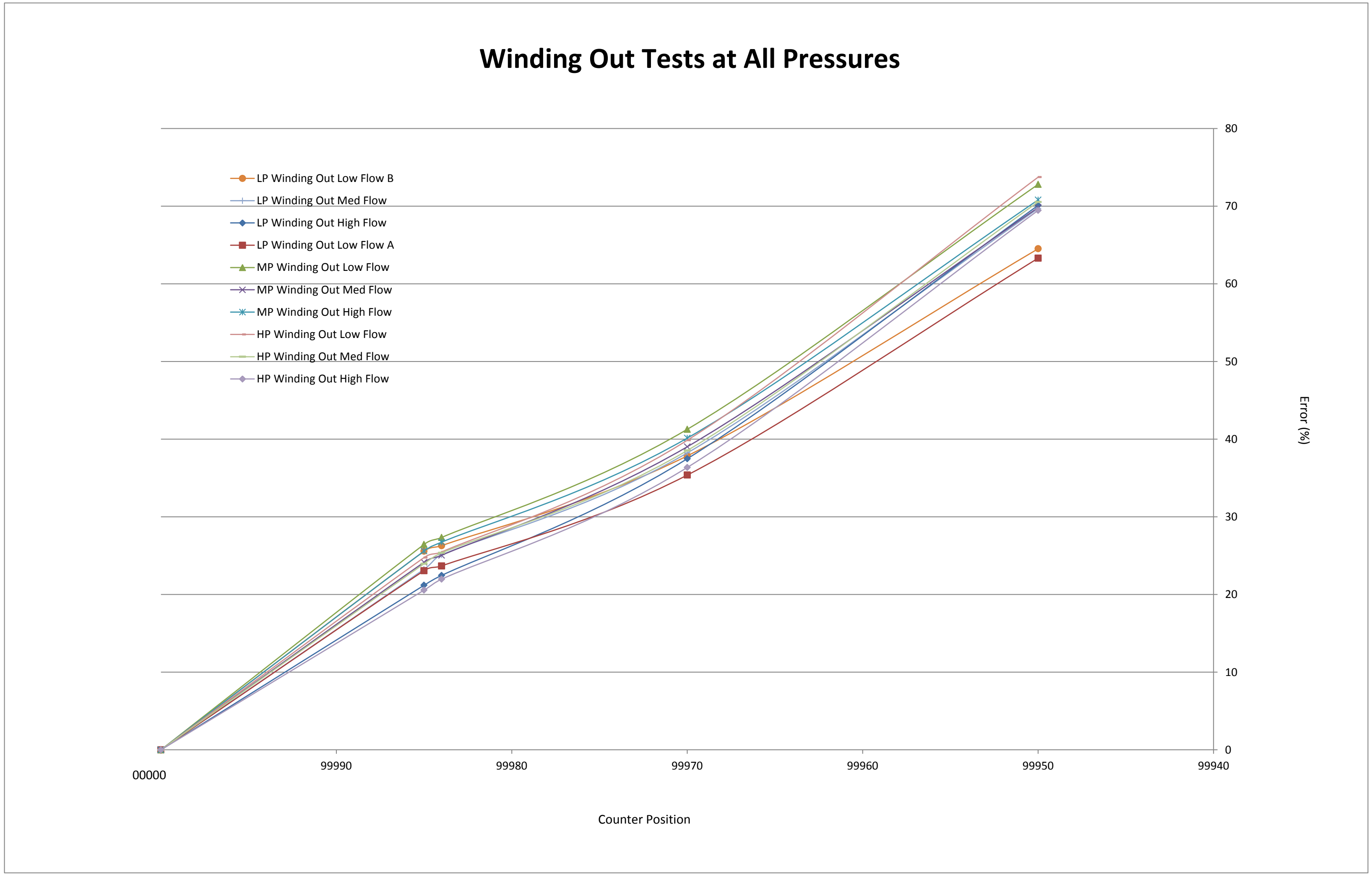
6.14 – All Tests (High Pressure)



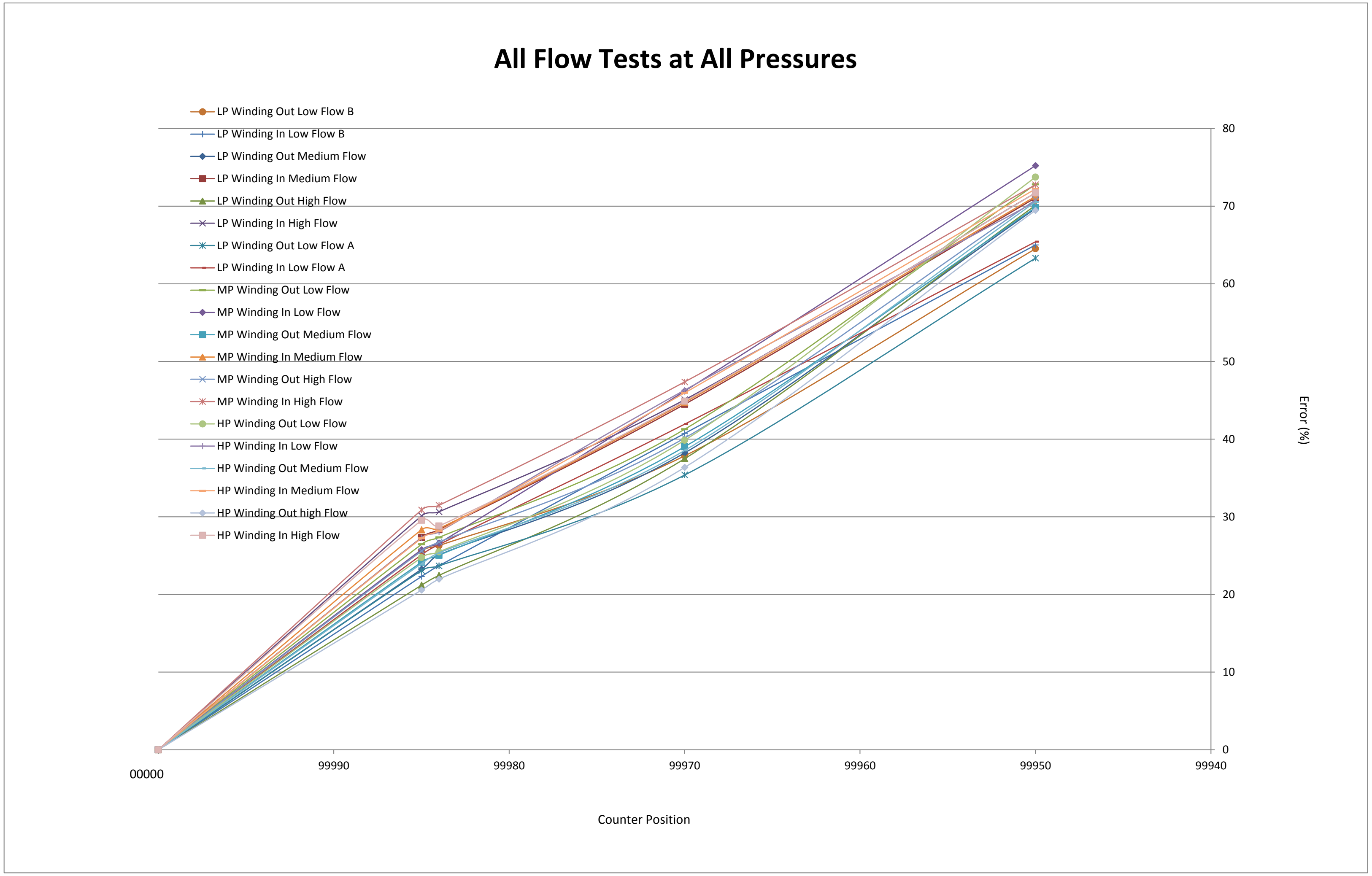
6.15 – All Tests (Winding In Orifice Plate)



6.16 – All Tests (Winding Out Orifice Plate)



6.17 – All Tests



7.0 SITE TEST OBSERVATION & DISCUSSION

7.1 Introduction

During the review of all site test data, three key areas became apparent.

1. Obtaining representative test data at low flow rates where the measurement uncertainty would be quite high;

   i) Typical differential pressure for SMER period (1) 13-15 mbar
   ii) Typical differential pressure for SMER period (2) 2-4 mbar

2. The instability of flow rate seen during some of the test durations.

3. The different flow error values that were generated at the same conditions by either "winding in" or "winding out" the orifice plate (Section 5.2, Figure 5.3 and Appendix C refer).

Each of these areas is further considered in more detail below.

7.2 Representative Low Flow Test Data

If typically, reference is made to the test results graph 6.15 (tabulated summary – Figure 7.1 refers), where all flows tests have been plotted for the "Winding-in Orifice Plate" operation, it can be clearly seen that;

- For the SMER period (1) 99985 counter reading plots, the three most obvious low error values are those representing the low flow test data (at typically 13-15 mbar). However, the CFD results for these test points (section 8 refers) agree favourably and for that reason there is no justification to exclude these site test values from further review.

- For the SMER period (2) 99950 counter reading plots, the two most obvious low error values (Tests 9 & 11) are those again, representing the low flow test data (at typically 2-4 mbar). However, in this case the CFD results for these test points (section 8 refers) record a significant discrepancy which potentially casts doubt over the acceptability of these site test values.

- Whilst not as obvious, the same can be said of the SMER period (2) Test 1 (medium pressure/low flow) which can be seen to fall "typically" within the main spread of the data set but much higher (in relation) to the other flow results. As in (2), the CFD result for this test point (section 8 refers) records a significant discrepancy which again, potentially casts doubt over the acceptability of this site value.

For additional reference, the typical differential pressures seen at both the medium and high flow are recorded as follows;

- Medium Flow;

  i) Typical differential pressure for SMER period (1) 110-124 mbar
  ii) Typical differential pressure for SMER period (2) 19-21 mbar

- High Flow;

  iii) Typical differential pressure for SMER period (1) 270-280 mbar
  iv) Typical differential pressure for SMER period (2) 40-43 mbar

7.3 Flow Instability

It was noted that the flow stability (difference between the test start and finish flows) observed throughout individual tests, varied on occasions and therefore had an effect on the value of reference flow rate used within the calculation of test errors (Section 5.4 refers);

Test 1	≈4%
Test 2	≈4%
Test 3	≈7%
Test 4	≈4%
Test 6	≈3%
Test 7	≈12%
Test 8-	≈4%
Test 9-	≈1%
Test 10-	≈11%
Test 11-	≈8%

7.4 "Winding-In" versus "Winding-Out" Orifice Plate Position

As previously identified within section 5.2 (and Figure 5.3), it was observed during the benchmarking visit that the positioning of the orifice plate varied (with respect to being either to the left or to the right of the centre line) when being "wound-in" and "wound-out" of the fitting.

As can be seen in Figure 5.3 (Test 3 – High Flow/Mid Pressure), the relative orifice plate position produces different flow errors for the same counter reading for example;

Counter Reading	Winding In (Error %)	Winding Out (Error %)
99985 (SMER Period 1)	30.873	25.59
99950 (SMER Period 2)	72.755	70.802

From discussions with the personnel involved, it would appear that the Maintenance Personnel (following orifice plate inspection/change-out) "wind-in" the orifice plate to the counter position.

Practically, this makes sense in that it would illogical (but not inconceivable) that the Maintenance Personnel would not "wind-in" the orifice plate to the stop and then "wind-out" again to the counter position.

With this in mind, it is the view and assumption of the Appointed Independent Expert that the "winding-in" error values should be used as the basis for both SMER period error evaluations.

7.5 Test Summary – SMER Period 1 (Counter Reading 99985)

From review of the test results, it can be seen that a majority of the test results follow a very similar response profile and show good agreement with the CFD modelling (section 8 refers). Therefore, there is no reason to disregard any of the site testing results from this review. Interestingly, Tests 9 and 11 (low flow A & B) are the most remote which could be due to the low differential pressures seen at this test point (≈15 bar).

7.6 Test Summary – SMER Period 2 (Counter Reading 99950)

From review of the test results, it can be seen that 70% of the test results follow a similar response profile and good agreement with the CFD modelling (section 8 refers) with the following exceptions;

- Test 1 – Medium Pressure / Low Flow
- Test 9 – Low Pressure / Low Flow
- Test 11 – Low Pressure / Low Flow

As these site tests were performed at such high measurement uncertainty due to the extremely low differential pressures (2-4 mbar) and the CFD results for these test points (section 8 refers) record such a significant discrepancy, it is the opinion of the Independent Technical Expert that these site test values are considered unrepresentative for use within the final correction factor calculation.

TEST 9 - LOW FLOW (A) / LP		**TEST 11** - LOW FLOW (B) / LP		**TEST 8** - MED FLOW / LP		**TEST 10** - HIGH FLOW / LP	
Counter Postion	Error (%)	Counter Postion	Error (%)	Counter Postion	Error (%)	Counter Postion	Error (%)
99950	65.412	99950	65	99950	71.067	99950	71.709
99970	41.926	99970	40.73	99970	44.488	99970	45.072
99984	26.431	99984	23.703	99984	28.328	99984	30.647
99985	25.102	99985	22.308	99985	27.328	99985	30.106
100000	0	100000	0	100000	0	100000	0
		TEST 1 - LOW FLOW / MP		**TEST 2** - MED FLOW / MP		**TEST 3** - HIGH FLOW / MP	
		Counter Postion	Error (%)	Counter Postion	Error (%)	Counter Postion	Error (%)
		99950	75.213	99950	71.26	99950	72.755
		99970	46.184	99970	44.719	99970	47.369
		99984	26.606	99984	28.492	99984	31.481
		99985	25.749	99985	28.325	99985	30.873
		100000	0	100000	0	100000	0
		TEST 6 - LOW FLOW / HP		**TEST 4** - MED FLOW / HP		**TEST 7** - HIGH FLOW / HP	
		Counter Postion	Error (%)	Counter Postion	Error (%)	Counter Postion	Error (%)
		99950	70.554	99950	72.209	99950	71.7
		99970	46.313	99970	45.949	99970	44.882
		99984	28.066	99984	28.175	99984	28.819
		99985	27.296	99985	27.236	99985	29.547
		100000	0	100000	0	100000	0

Figure 7.1 – Tabulated Summary of “Winding IN” Site Testing Results

8.0 COMPUTATIONAL FLUID DYNAMICS

8.1 Introduction

In order to provide an additional reference to support the "trend" of the site test results, the Appointed Independent Expert recommended a programme of flow system modelling by Computation Fluid Dynamics (CFD) be included as part of the SMER review process.

The requirement and scope for this programme of CFD activity comprised two "key" processes;

1. A detailed CFD modelling process progressed by an Industry Expert and the subsequent delivery of a fully encompassing technical report.

2. A "Peer Review" process progressed by an Industry Expert that is specifically ISO 9001:2008 certified for flow modelling and software.

The completion and acceptance of these processes within the SMER review would provide the following benefits;

A. An additional "independent" review of the flow measurement error "trends" to those derived from site testing which can be used to validate the results.

B. The confidence that the CFD modelling process was peer reviewed by another independent third party.

C. The SMER findings would be the result of the work completed by several independent sources that include both practical site testing and theorised modelling.

8.2 CFD Modelling Provider

The CFD modelling work was completed by Professor W Malalasekera BSc PhD DIC, Professor of Computational Fluid Flow & Heat Transfer at Loughborough University.

8.3 Peer Review Provider

The peer review process was prepared by Marc Laing MEng AMIChemE and approved by Dr Michael Reader-Harris of TVU SUD NEL, East Kilbride, Scotland.

8.4 CFD Methodology

- The Appointed Independent Expert provided all dimensional and operating data to Professor Malalasekera to enable the CFD model to be constructed.

- The Appointed Independent Expert provided 3 separate "ISO-5167 compliant" flow scenarios (from archive Aberdeen off-take measurement data) ***excluding the actual differential pressure value***, to validate the CFD model (i.e. commencement benchmark against "blind tests"). This requirement additionally satisfies point 4 of the British Gas TMI e-mail dated 24th August 2012 (Figures 8.4.1, 8.4.2 and 8.4.3 refer).

- When the CFD model had been satisfactorily demonstrated against associated "ISO-5167 compliant" flow data, the Appointed Independent Expert provided a series (from the 99970 series of site testing results) "non-compliant ISO-5167" (i.e. "in error" scenarios) to further validate CFD model in this "error mode". Again, this requirement additionally satisfies point 4 of the British Gas TMI e-mail dated 24th August 2012 (Figure 8.4.4 refers).

- When the CFD model had been satisfactorily demonstrated against associated "ISO-5167 compliant & non-compliant" flow data, the Appointed Independent Expert provided the full 99985 and 99950 counter reading SMER data for associated modelling and completion of a R1 report for further peer review.

- On completion of the R1 CFD report it was issued to TUV SUD NEL for peer review and issue of comments and recommendations.

- Incorporate associated peer review comments within the CFD report (R2).

- Peer review by TUV SUD NEL of R2 CFD report.

- Issue the finalised CFD report (R3), in conjunction with the Appointed Independent Expert SMER report, to the JO representatives for review.

- Professor Malalasekera to present the findings of his CFD report R3 to the JO representatives if required.

8.5 CFD Report R1 (October 2012) Results

Tables 8.5.1 and 8.5.2 tabulate the results obtained within the CFD R1 report (prior to the peer review and update to R2) for SMER Period 1 (counter reading 99985).

Tables 8.5.3 and 8.5.4 tabulate the results obtained within the CFD R1 report (prior to the peer review and update to R2) for SMER Period 2 (counter reading 99950).

Case 1 – With correct orifice position and a flow rate of 414.2697 m^3/h				
	Differential pressure DP (mbar)	% Error between CFD and experimental	Uncertainty of measurements	Difference in error between simulations
Measured value	12.94			
CFD Simulation 1 – Grid 1 (2324882 cells)	12.74	1.5%	5 – 6%	
CFD Simulation 2 – Grid 2 (2872671 cells)	12.82	0.9%	5 – 6%	between 1 & 2 0.6%
CFD Simulation 3 – Grid 3 (2997933 cells)	12.85	0.6%	5 – 6%	between 2 & 3 0.3%

Figure 8.4.1 – Comparison of CFD Results (Case 1)

Case 2 – With correct orifice position and a flow rate of 567.374 m^3/h				
	Differential pressure DP (mbar)	% Error between CFD and experimental	Uncertainty of measurements	Difference in error between simulations
Measured value	24.43			
CFD Simulation 1 – Grid 1 (2324882 cells)	24.50	0.2%	5 – 6%	
CFD Simulation 2 – Grid 2 (2872671 cells)	24.57	0.5%	5 – 6%	between 1 & 2 0.3%
CFD Simulation 3 – Grid 3 (2997933 cells)	24.50	0.2%	5 – 6%	between 2 & 3 0.3%

Figure 8.4.2 – Comparison of CFD Results (Case 2)

Case 3 – With correct orifice position and a flow rate of 137047.908 m^3/h				
	Differential pressure DP (mbar)	% Error between CFD and experimental	Uncertainty of measurements	Difference in error between simulations
Measured value	439.41			
CFD Simulation 1 – Grid 1 (2347212 cells)	437.87	0.3%	Less than 1%	
CFD Simulation 2 – Grid 2 (2599239 cells)	437.92	0.3%	Less than 1%	between 1 & 2 0%
CFD Simulation 3 – Grid 3 (3011613 cells)	442.41	0.6%	Less than 1%	between 2 & 3 0.3%

Figure 8.4.3 – Comparison of CFD Results (Case 3)

Case id	Case considered and identification details	Actual flow rate (m^3/h)	Density (kg/m^3)	Viscosity (Pa.s)	Predicted differential pressure (mbar)	Measured differential pressure	Error percentage	Remarks
970-1	**CASE 99970 – TEST 3** Incorrect position - Eccentric dimensions are A = 139.1, B=25.5 mm (max used touching the wall). Flow rate Q=2430.7522 m^3/h	2430.7522 (139976.124)	57.585	0.0000124	**137.76**	140.19	1.73%	Uncertainty in measurements < 1.5%
970-2	**CASE 99970 – TEST 7** Incorrect position - Eccentric dimensions are A = 139.1, B=25.5 mm (max used touching the wall). Flow rate Q=2259.955 m^3/h	2259.955 (135576.895)	59.990	0.0000124	**125.44**	127.96	1.97%	Uncertainty in measurements < 2.0%
970-3	**CASE 99970 – TEST 8** Incorrect position - Eccentric dimensions are A = 139.1, B=25.5 mm (max used touching the wall). Flow rate Q=1741.5158 m^3/h	1741.5158 (92506.608)	53.118	0.0000123	**61.10**	65.19	6.2%	Uncertainty in measurements < 1.5 %
970-4	**CASE 99970 – TEST 10** Incorrect position - Eccentric dimensions are A = 139.1, B=25.5 mm (max used touching the wall). Flow rate Q=2472.6176 m^3/h	2472.6176 (131209.380)	53.064	0.0000123	**130.98**	133.61	2.1 %	Uncertainty in measurements < 1.5 %

Figure 8.4.4 – Counter Reading 99970 CFD R1 Results (Test Cases)

Case id	Case considered and identification details	Actual flow rate (m^3/h) and (Mass flow rate, kg/h)	Density (kg/m^3)	Viscosity (Pa.s)	Predicted differential pressure (mbar)	Measured differential pressure	Error percentage	Remarks
985-1	**CASE 99985 – TEST 1** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	594.4561 (33696.1843)	56.684	0.0000124	**14.28**	13.784	3.5%	Uncertainty in measurements < 5 %
985-2	**CASE 99985 – TEST 2** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	1598.6628 (90950.2459)	56.892	0.0000124	**103.961**	103.136	0.7%	Uncertainty in measurements < 2 %
985-3	**CASE 99985 – TEST 3** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	2396.1463 (138132.993)	57.647	0.0000124	**236.815**	242.939	2.5%	Uncertainty in measurements < 1 %
985-4	**CASE 99985 – TEST 4** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	1540.5865 (92601.981)	60.108	0.0000125	**101.756**	102.495	0.7%	Uncertainty in measurements < 2 %

Figure 8.5.1 – Counter Reading 99985 CFD Results R1 (Cases 1 - 4)

985-5	**CASE 99985 – TEST 6** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	534.9225 (32179.62)	60.158	0.0000125	**12.111**	12.062	0.4%	Uncertainty in measurements < 6 %
985-6	**CASE 99985 – TEST 7** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	2174.3146 (130547.98)	60.041	0.0000125	**202.847**	208.331	2.6%	Uncertainty in measurements < 1 %
985-7	**CASE 99985 – TEST 8** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	1729.112 (91847.114)	53.118	0.0000123	**112.114**	112.566	0.4%	Uncertainty in measurements < 1.5%
985-8	**CASE 99985 – TEST 9** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	609.996 (32754.048)	53.695	0.0000123	**14.35**	14.067	2.0%	Uncertainty in measurements < 5 %
985-9	**CASE 99985 – TEST 10** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	2415.2228 (128274.12)	53.111	0.0000123	**221.774**	217.578	1.9%	Uncertainty in measurements < 1 %
985-10	**CASE 99985 – TEST 11** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	648.0378 (34565.349)	53.338	0.0000123	**15.93**	15.981	0.3%	Uncertainty in measurements < 4.5 %

Figure 8.5.2 – Counter Reading 99985 CFD Results R1 (Cases 6 - 11)

Case id	Case considered and identification details	Actual flow rate (m^3/h) and (Mass flow rate, kg/h)	Density (kg/m^3)	Viscosity (Pa.s)	Predicted differential pressure (mbar)	Measured differential pressure	Error percentage	Remarks
950-1	**CASE 99950 – TEST 1** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	588.60 (33364.2584)	56.684	0.0000124	**1.75**	1.39	25%	Uncertainty in measurements ≈ 6 – 7%
950-2	**CASE 99950 – TEST 2** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	1619.6945 (92032.9718)	56.821	0.0000124	**16.91**	16.07	5.2%	Uncertainty in measurements ≈ 6 %
950-3	**CASE 99950 – TEST 3** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	2459.8613 (141573.504)	57.553	0.0000124	**35.75**	37.28	4.1%	Uncertainty in measurements < 5 %
950-4	**CASE 99950 – TEST 4** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	1564.3494 (94042.855)	60.116	0.0000125	**13.60**	14.60	6.8%	Uncertainty in measurements < 6 %

Figure 8.5.3 – Counter Reading 99950 CFD Results R1 (Cases 1 - 4)

950-5	**CASE 99950 – TEST 6** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	541.2844 (32562.3366)	60.157	0.0000125	**1.68**	1.854	9.1%	Uncertainty in measurements ≈ 6 – 7%
950-6	**CASE 99950 – TEST 7** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	2284.8572 (137055.98)	59.984	0.0000125	**35.52**	33.42	6.20%	Uncertainty in measurements < 5 %
950-7	**CASE 99950 – TEST 8** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	1748.498 (92917.081)	53.118	0.0000123	**18.45**	17.43	5.8%	Uncertainty in measurements < 5 %
950-8	**CASE 99950 – TEST 9** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	608.80 (32689.86)	53.695	0.0000123	**2.42**	2.83	14.4%	Uncertainty in measurements ≈ 6 – 7%
950-9	**CASE 99950 – TEST 10** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	2506.863 (133026.445)	53.064	0.0000123	**36.61**	34.96	4.7%	Uncertainty in measurements < 5 %
950-10	**CASE 99950 – TEST 11** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	633.819 (33806.983)	53.338	0.0000123	**2.61**	3.07	14.9%	Uncertainty in measurements ≈ 6 – 7%

Figure 8.5.4 – Counter Reading 99950 CFD Results R1 (Cases 6 - 11)

8.6 CFD Report R1 (October 2012) 99985 Results Summary

It can be seen from tables 8.5.1 and 8.5.2, the value of differential pressure obtained from CFD modelling for all test cases compare favourably with those obtained from the site testing.

It should be noted that the CFD modelling error results (%) are stated as differential pressure (mbar) and not flow rate.

8.7 CFD Report R1 (October 2012) 99950 Results Summary

It can be seen from tables 8.5.3 and 8.5.4, the value of differential pressure obtained from CFD modelling for all test cases "mostly" compare favourably with those obtained from the site testing given the high flow measurement uncertainty associated with such low differential pressures. Tests #1, #9 and #11 are obvious exceptions but the mitigating circumstances being the measured differential pressures are typically < 3 mbar.

Again, it should be noted that the CFD modelling error results (%) are stated as differential pressure (mbar) and not flow rate.

8.8 CFD Report R1 (October 2012) Peer Review Comments

The peer review of the CFD R1 Report was completed by TUV SUD NEL and issued on the 15th March 2013. Following receipt of the TUV SUD NEL peer review comments, a teleconference was arranged for 14th May 2013 to discuss the recommendations and agree the definitive way forward for final peer acceptance. It was agreed that the following revisions be incorporated within the final CFD report;

1 Reduction in the size of the CFD model in terms of pipe lengths. In the opinion of TUV SUD NEL the model should be 2D upstream and 10D downstream and no thermowell included within the model.

   Note; In the construction of the original model pipe geometry, a 2 m pipe length was used for the upstream side of the orifice plate and a separate pipe flow calculation carried out to obtain the inlet flow profile. On the downstream side the thermowell was placed at 9D length. The pipe bends after 18D from the orifice location and after the bend, a 15m pipe length was used to complete the geometry.

2 Re-mesh the model using hexahedral elements where possible.

3 Refine the elements around the sharp edge of the orifice plate.

4 Demonstrate mesh independence.

8.9 CFD Report R2 (May 2013)

The CFD report was revised (R2 – May 2013) to incorporate the peer review comments (section 8.8. refers).

The original model used for case 99985 (SMER period 1) was modified using 2D upstream and 10D downstream (without the thermowell) and all tests were re-run with the new short model recommended by TUV SUD NEL (section 8.8 – point 1 refers).

For TUV SUD NEL "short model" - Two grid (mesh) sizes were used in the calculations (grid size 1 = 2.78 million cells and grid size 2 = 2.88 million cells). In these grids, boundary layer meshes were incorporated to maintain y+, hexahedral elements were used as much as possible (section 8.8 – point 2 refers) and refined tetrahedral mesh densities were used around the orifice sharp edge area of the carrier geometry (section 8.8 – point 3 refers).

The original model ("long model") was re-meshed (grid size 1 = 2.44 million cells and grid size 2 = 2.9 million cells) to incorporate boundary layer meshes to maintain y+. Hexahedral elements were used as much as possible and refined tetrahedral mesh densities were used around orifice sharp edge area of the carrier geometry.

All results from the above models were compared with the site test results (experimental data).

It was found that the TUV SUD NEL "short model" (grid size 2 = 2.88 million cells) whilst finer than the original "long model" (grid size 1 = 2.44 million cells) did not yield a "closer" experimental match. Based on these results, the Professor concluded that the longer model, based on original geometry was more accurate than the shorter model (recommended by TUV SUD NEL). Therefore, it was the Professors opinion that the original long model (with the added benefit of the enhanced grid sizes) be used as the preferred option to conduct all other test cases.

It was also observed that a third grid was required to demonstrate mesh independence (section 8.8 – point 4 refers) where the differences between results from the first two grids is less than 1% (or as near as can be accommodated).

It was further noted from the vector plots produced, that when the orifice plate is severely misaligned, the resulting flow is more "wall bound – wall jet like" flow and in this case the flow does not recover to a standard pipe flow profile for a long distance which demonstrates that the original "long model" is required (and most suited) for the successful predictions required for this review.

8.10 CFD Report R2 (May 2013) Peer Review

The peer review of the CFD R2 Report was completed by TUV SUD NEL and issued on the 31st July 2013. The following comments were stated to which the Professors replies follow in ***"blue italics"***.

NEL Comment 1 - For the long model at any rate CFD grid independence has not been achieved; so the contention that the long model is required has not been proved.

The decision to use a long model to perform calculations was based on several reasons. Many published work on CFD modelling of orifice plate flows indicated that more than 20D downstream pipe lengths has to be used to achieve successful calculations. Two ESDU reports [see references 4 and 5] which have been endorsed by an eminent IMechE panel of experts recommended to use a length of more than 200D downstream. This length appears to depend on the actual diameter of the pipe, type of orifice plate used and other flow conditions considered in various modelling efforts. However, some other researchers have used shorter downstream lengths. For example Shah et al. [see reference 6] in their work have used 40D. Erdal and Anderssson [see reference 6] have used 16D. No published work could be found to use 10D downstream length. Equations solved in CFD calculations are elliptic equations and all boundary conditions have to be specified to obtain solutions. The main requirement is that outflow flow boundary conditions are normally imposed in numerical flow calculations where the axial gradients are zero. This allows the extrapolation of data from the interior to use as outlet boundary conditions. To satisfy this, it is required to use a long downstream length. It should be noted that this requirement is not a physical requirement, it is a numerical requirement. Such examples could be found elsewhere in numerical calculations. When a buoyant flow in a compartment is numerically modelled an artificial domain outside the doorway of the compartment has to be included in the calculation to achieve successful results [see references 7 and 8]. Modelling only the compartment (room) and imposing pressure boundary condition at the doorway will not produce successful CFD simulations. When an explosion experiment conducted in a laboratory scale explosion chamber is considered in CFD modelling the domain outside the explosion chamber has to be included in the calculation to achieve successful results [see reference 9]. Therefore the need to include a larger downstream length in an orifice flow calculation is for numerical stability. In the cases considered in the present study it was clear from the outset that due to severe miss-alignment of the orifice plate the flow downstream of the orifice plate is very much asymmetric and wall bounded and flow would not recover to its fully developed profile for a long distance. Therefore it was more sensible to use full geometrical features as it appeared in the actual installation rather *than using an approximately shorter geometry. This could be further elaborated by showing some results from a shorter model attempt used during the review exercises. The reviewers recommended the use of a shorter model (2D upstream 10D downstream). This was undertaken in the revisions and proved to be unsuccessful as shown in the Appendix of the report in terms of producing experimentally obtained results. Shown in Figure 8.10.1 below is the velocity magnitude at the out of the 99985 short model using a 10D downstream pipe length. As it can be seen the outlet velocity magnitude distribution is clearly asymmetric and not recovered to a general pipe flow profile. Therefore it would require the use of a longer length to impose suitable outlet boundary conditions in the simulations and therefore the use of the current modelling strategy is justified.*

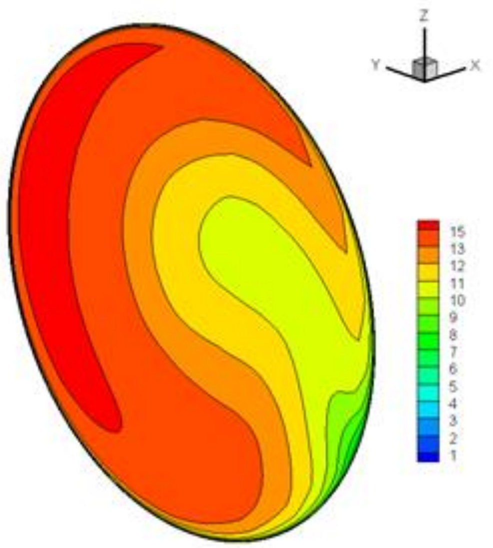


Figure 8.10.1 – Contour Plot of Outlet Velocity Magnitude from a Short Model Simulation of Case 99985 – Test 3.

NEL Comment 2 - There is generally quite good agreement between experiment and CFD but grid independence remains to be achieved.

It was shown in the report that the difference between the results of Grid 2 and Grid 3 in each case is less than 1%. In many cases the difference is in fact less than 0.5%. It is reasonable to conclude that the finer mesh results have reached a grid independent result. With three predicted CFD results a rough approximation of the final result could be made using generalized Richardson extrapolation. This was not considered because a constant refinement ratio could not be identified for all cases. The ultimate test for a numerical model is to compare results with available *experimental results. It has been shown that the results obtained with the last grid (Grid 3) in each case agree reasonably well with experimental results.*

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To summarise, there remains two areas for which NEL and Professor Malalasekera technical views differ;

1- Long versus short model preference.

2- Whether "Grid Independence" has been achieved.

The Professor has provided extremely powerful responses to each of these areas, additionally referencing other research papers in support of his views.

The professors report R3 (August 2013) incorporates an additional Appendix (B) in which he provides detailed information and guidance on mesh sizing in response to the NEL comments.

As the main aim of the CFD work was commissioned to support the site testing "error trend", the achieved grid independence to typically 0.5% is considered acceptable by the Appointed Independent Expert and satisfied that no "additional value" can be gained from further CFD activities, therefore the Professors final report (R3 – August 2013) should be considered as acceptable.

8.11 CFD Report R2 (May 2013) / R3 (August 2013) 99985 Results Summary

It can be seen from tables 8.5.5, 8.5.6 and 8.5.7, that the value of differential pressure obtained from CFD modelling R2 for all test cases, compare very favourably with those obtained from the site testing and of a similar value to those calculated from the R1 CFD modelling (CFD v Site Test Results – Summary Table 8.5.8 refers).

8.12 CFD Report R2 (May 2013) / R3 (August 2013) 99950 Results Summary

It can be seen from tables 8.5.9, 8.5.10 and 8.5.11, the value of differential pressure obtained from CFD modelling R2 for most test cases, compare very favourably with those obtained from the site testing and of a similar value to those calculated from the R1 CFD modelling given the high flow measurement uncertainty associated with such low differential pressures.

It is most interesting that Tests #1, #9 and #11 are much more obvious exceptions than originally obtained from the R1 results (CFD v Site Test Results – Summary Table 8.5.12 refers).

Case id	Case considered and identification details	Actual flow rate (m^3/h) and (Mass flow rate, kg/h)	Density (kg/m^3) and viscosity	Model variation	Predicted differential pressure (mbar)	Measured differential pressure	Error %	Remarks	% Difference of error between models (1&2, 2&3)
985-1	**CASE 99985 – TEST 1** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	594.4561 (33696.1843)	56.684 1.24e-5	**Grid_1** **Grid_2** **Grid_3**	**14.68** **14.43** **14.40**	13.784	6.5% 4.7% 4.4%	Uncertainty in measurements < 5 %	- 1.8% 0.3%
985-2	**CASE 99985 – TEST 2** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	1598.6628 (90950.2459)	56.892 1.24e-5	**Grid_1** **Grid_2** **Grid_3**	**106.25** **104.71** **104.36**	103.136	3.0% 1.5% 1.2%	Uncertainty in measurements < 2 %	- 1.5% 0.3%
985-3	**CASE 99985 – TEST 3** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	2396.1463 (138132.993)	57.647 1.24e-5	**Grid_1** **Grid_2** **Grid_3**	**241.54** **237.72** **237.43**	242.939	0.5% 2.1% 2.2%	Uncertainty in measurements < 1 %	- 1.6% 0.1%

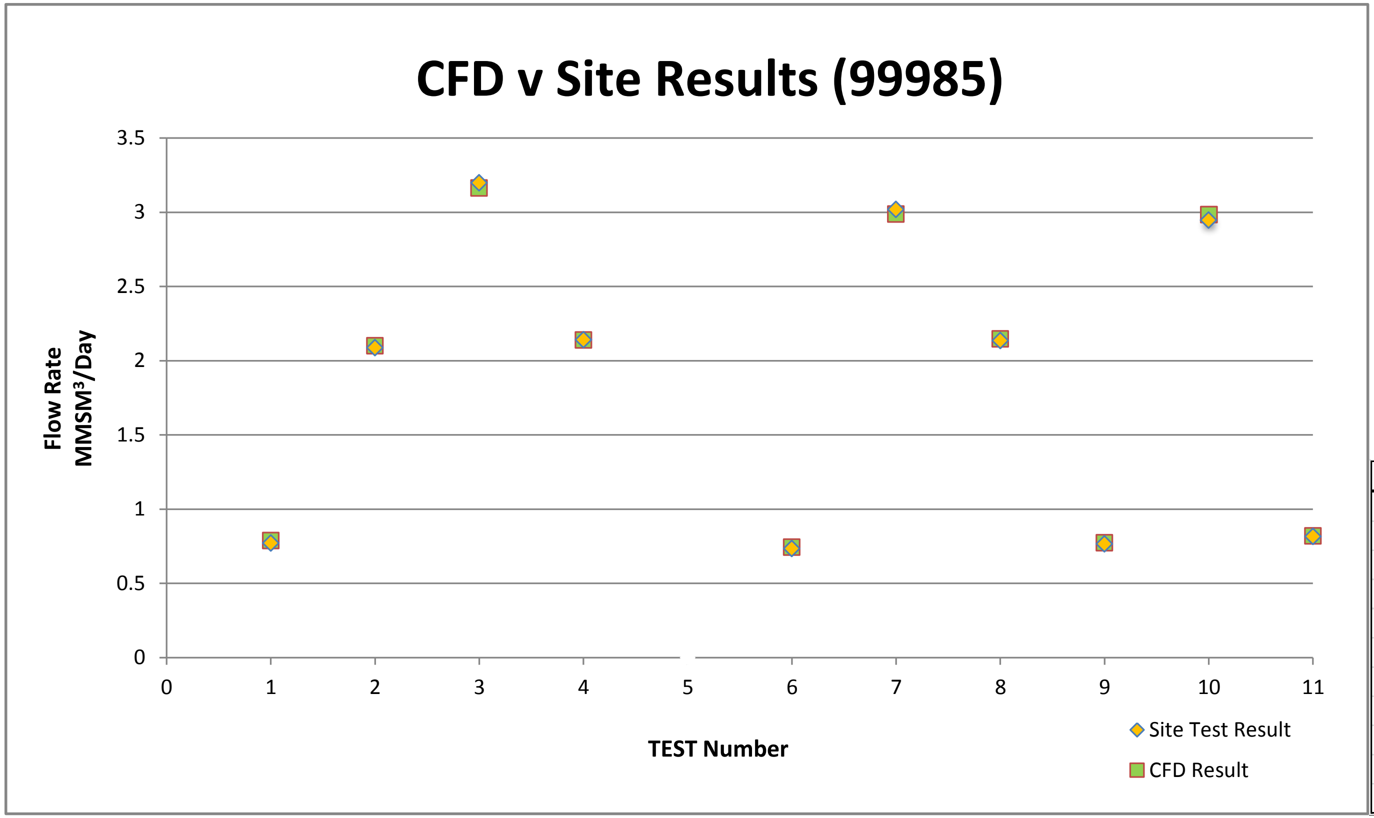
Figure 8.5.5 – Counter Reading 99985 CFD Results R2 (Cases 1 - 3)

985-4	**CASE 99985 – TEST 4** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	1540.5865 (92601.981)	60.108 1.25e-5	**Grid_1** **Grid_2** **Grid_3**	**104.23** **102.56** **102.43**	102.495	1.6% 0% 0%	Uncertainty in measurements < 2 %	- 1.6% 0%
985-6	**CASE 99985 – TEST 6** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	534.9225 (32179.62)	60.158 1.25e-5	**Grid_1** **Grid_2** **Grid_3**	**12.62** **12.31** **12.38**	12.062	4.6% 2.1% 2.6%	Uncertainty in measurements < 6 %	- 2.5% 0.5%
985-7	**CASE 99985 – TEST 7** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	2174.3146 (130547.98)	60.041 1.25e-5	**Grid_1** **Grid_2** **Grid_3**	**207.52** **203.88** **203.99**	208.331	0.3% 2.1% 2.1%	Uncertainty in measurements < 1 %	- 1.8% 0%
985-8	**CASE 99985 – TEST 8** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	1729.112 (91847.114)	53.118 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**116.05** **114.17** **113.87**	112.566	3.1% 1.4% 1.1%	Uncertainty in measurements < 1.5%	- 1.7% 0.3%
985-9	**CASE 99985 – TEST 9** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	609.996 (32754.048)	53.695 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**14.63** **14.39** **14.35**	14.067	4.0% 2.3% 2.0%	Uncertainty in measurements < 5 %	- 1.7% 0.3%

Figure 8.5.6 – Counter Reading 99985 CFD Results R2 (Cases 4 - 9)

985-10	**CASE 99985 – TEST 10** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	2415.2228 (128274.12)	53.111 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**226.40** **222.93** **223.02**	217.578	4.0% 2.4% 2.5%	Uncertainty in measurements < 1 %	- 0.7% 0.1%
985-11	**CASE 99985 – TEST 11** Incorrect position - Eccentric dimensions are A = 87.23, B=17.5 mm.	648.0378 (34565.349)	53.338 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**16.40** **16.12** **16.08**	15.981	2.6% 0.8% 0.6%	Uncertainty in measurements < 4.5 %	- 1.8% 0.2%

Figure 8.5.7 – Counter Reading 99985 CFD Results R2 (Cases 10 - 11)



TEST	Site Flow Rate	CFD Flow Rate	Δ (%)
1	0.771	0.788	2.2
2	2.087	2.100	0.6
3	3.199	3.164	-1.1
4	2.14	2.140	-0.01
5	Test Aborted		
6	0.734	0.744	1.3
7	3.019	2.987	1.05
8	2.135	2.147	0.55
9	0.766	0.774	1
10	2.947	2.984	1.25
11	0.816	0.818	0.3

Figure 8.5.8 – CFD v Site Test Result Summary Table (99985)

Case id	Case considered and identification details	Actual flow rate (m^3/h) and (Mass flow rate, kg/h)	Density (kg/m^3) and viscosity	Model variation	Predicted differential pressure (mbar)	Measured differential pressure	Error %	Remarks	% Difference of error between models (1&2, 2&3)
950-1	**CASE 99950 – TEST 1** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	588.60 (33364.2584)	56.684 1.24e-5	**Grid_1** **Grid_2** **Grid_3**	**2.08** **1.98** **1.99**	1.39	**49.6%** **42.4%** **43.1%**	Uncertainty in measurements < 5 %	- **7.2%** **0.3%**
950-2	**CASE 99950 – TEST 2** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	1619.6945 (92032.9718)	56.821 1.24e-5	**Grid_1** **Grid_2** **Grid_3**	**17.03** **16.23** **16.32**	16.07	**5.9%** **0.9%** **1.5%**	Uncertainty in measurements < 2 %	- **4.4%** **0.6%**
950-3	**CASE 99950 – TEST 3** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	2459.8613 (141573.504)	57.553 1.24e-5	**Grid_1** **Grid_2** **Grid_3**	**38.47** **38.02** **37.98**	37.28	**3.1%** **1.9%** **1.8%**	Uncertainty in measurements < 1 %	- **1.2%** **0.2%**

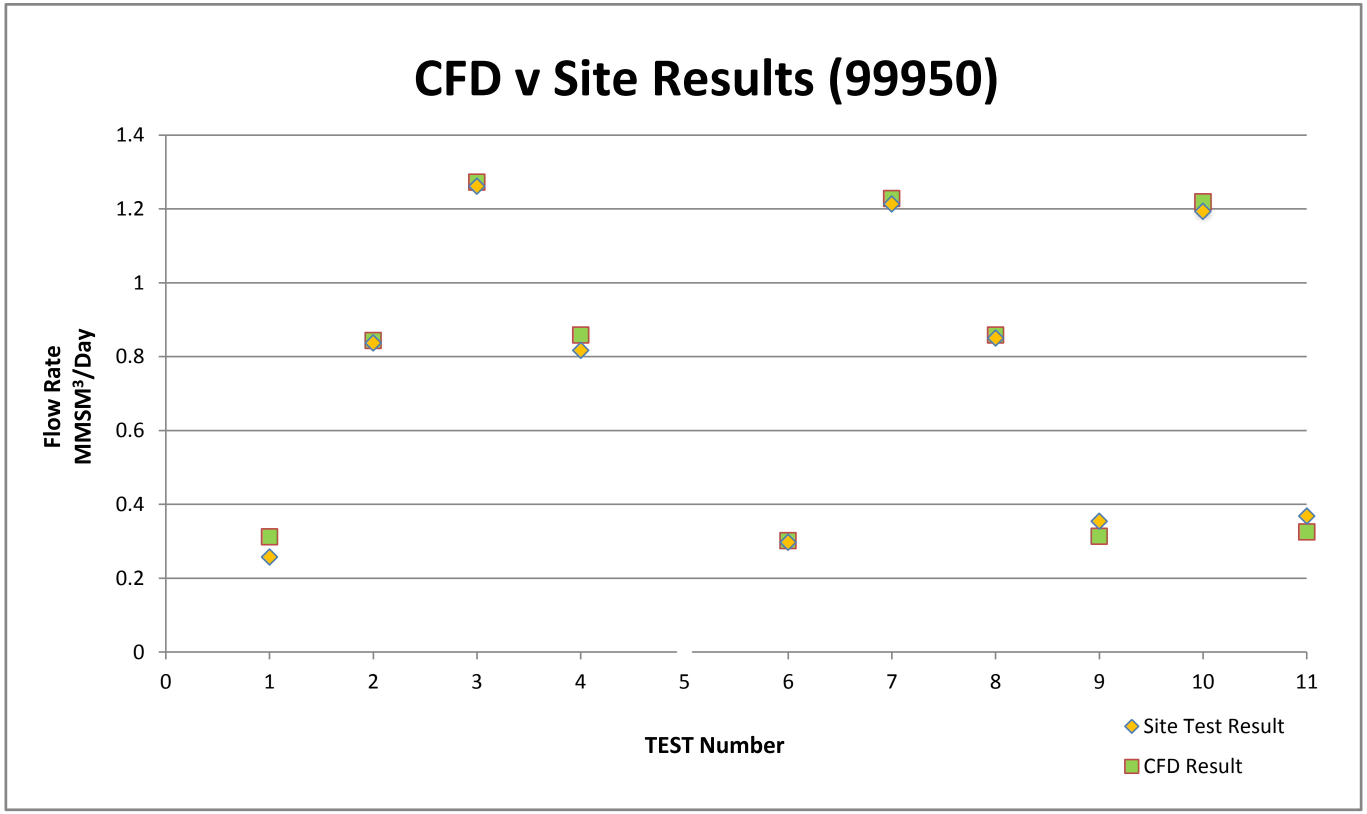
Figure 8.5.9 – Counter Reading 99950 CFD Results R2 (Cases 1 - 3)

950-4	**CASE 99950 – TEST 4** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	1564.3494 (94042.855)	60.116 1.25e-5	**Grid_1** **Grid_2** **Grid_3**	**16.79** **16.02** **16.09**	14.60	15.0% 9.7% 10.2%	Uncertainty in measurements < 2 %	- 5.3% 0.5%
950-6	**CASE 99950 – TEST 6** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	541.2844 (32562.3366)	60.157 1.25e-5	**Grid_1** **Grid_2** **Grid_3**	**2.01** **1.92** **1.91**	1.854	8.6% 3.7% 3.2%	Uncertainty in measurements < 6 %	- 4.9% 0.5%
950-7	**CASE 99950 – TEST 7** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	2284.8572 (137055.98)	59.984 1.25e-5	**Grid_1** **Grid_2** **Grid_3**	**35.90** **34.32** **34.28**	33.42	7.4% 2.6% 2.5%	Uncertainty in measurements < 1 %	- 4.8% 0.1%
950-8	**CASE 99950 – TEST 8** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	1748.498 (92917.081)	53.118 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**18.54** **17.84** **17.77**	17.43	6.3% 2.3% 1.9%	Uncertainty in measurements < 1.5%	- 4.0% 0.4%
950-9	**CASE 99950 – TEST 9** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	608.80 (32689.86)	53.695 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**2.27** **2.18** **2.18**	2.83	19.7% 22.9% 22.9%	Uncertainty in measurements < 5 %	- 3.2% 0%

Figure 8.5.10 – Counter Reading 99950 CFD Results R2 (Cases 4 - 9)

950-10	**CASE 99950 – TEST 10** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	2506.863 (133026.445)	53.064 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**37.95** **36.57** **36.43**	34.96	8.5% 4.6% 4.2%	Uncertainty in measurements < 1 %	- 3.9% 0.4%
950-11	**CASE 99950 – TEST 11** Incorrect position - Eccentric dimensions are A = 210.5 mm, B=22.5 mm.	633.819 (33806.983)	53.338 1.23e-5	**Grid_1** **Grid_2** **Grid_3**	**2.44** **2.35** **2.35**	3.07	20.5% 23.4% 23.4%	Uncertainty in measurements < 4.5 %	- 2.9% 0%

Figure 8.5.11 – Counter Reading 99950 CFD Results R2 (Cases 10 - 11)



TEST	Site Flow Rate	CFD Flow Rate	Δ (%)
1	0.257	0.312	21.55
2	0.837	0.843	0.75
3	1.261	1.272	0.9
4	0.817	0.859	5.1
5	Test Aborted		
6	0.297	0.302	1.6
7	1.213	1.228	1.25
8	0.85	0.858	0.95
9	0.354	0.313	-11.45
10	1.193	1.219	2.1
11	0.368	0.325	-11.7

Figure 8.5.12 – CFD v Site Test Result Summary Table (99950)

9.0 CORRECTION FACTOR CALCULATION SUMMARY

9.1 Introduction

Given the results of the site testing and the supportive CFD modelling analysis, the calculation methodology for the most appropriate measurement error value (and subsequent correction factor) is detailed within the following sections.

9.2 SMER Period 1

In the opinion of the Appointed Independent Technical Expert the site results (tabulated summary within figure 7.1 refers) appear to demonstrate that whilst there is no related trend to the difference in operating pressure, there does seem to be a distinct band of error values created by the difference in flow rate and prevalent only to the 99985 counter reading position.

- Low flow error value band (%) 22.308 – 27.296 (Typical ΔP = 13 - 15 mbar)
- Mid flow error value band (%) 27.236 – 28.325 (Typical ΔP = 110 - 124 mbar)
- High flow error value band (%) 29.547 – 30.873 (Typical ΔP = 270 - 280mbar)

Given the results of the site testing and CFD modelling (detailed within sections 6, 7 and 8), 3 options for which the determination of the most appropriate estimate of measurement error can be defined;

1. Use all site test results as valid contributions and calculate their average. This option equates to an under-read of 27.387%.
2. Use only those site test results that agree favourably with the CFD modelling results (section 7.6 refers). As all CFD modelling results are aligned favourably with the site tests then all test results should be considered representative. Therefore this option also equates to an under-read of 27.387%.
3. Use only those site test results that agree favourably with the CFD modelling results (section 7.6 refers) but in addition, only use the result set(s) that align with the "**average**" flow scenario (low, medium or high) that existed at the end of each day within the SMER period (tabulated data within Appendix E refers). This option therefore equates to three under-read error values;

Days where the average flow was designated low flow = 25.114%

Days where the average flow was designated mid flow = 27.630%

Days where the average flow was designated high flow = 30.175%

In the opinion of the Appointed Independent Technical Expert, Option 3 is the recommended method for the appropriate SMER Period 1 estimate of measurement error as the following criteria are met;

A. All site test results agree favourably with the CFD modelling analysis so therefore each one must be considered representative.

B. The application of "flow band" related error values will optimise the associated error value used for each day within the SMER period.

As the daily average flow equated to low and medium bands only (Appendix E refers), it is therefore recommended that the two flowing error values are used as the basis for the derivation of the estimated correction factor figures;

Low Flow Day Correction Factor = $\frac{\mathbf{100}}{\mathbf{100-25.114}} = \mathbf{1.335}$ (25.114%)

Mid Flow Day Correction Factor = $\frac{\mathbf{100}}{\mathbf{100-27.630}} = \mathbf{1.382}$ (27.630%)

9.3 SMER Period 2

As there was no apparent trend in the error values obtained for the 99950 counter reading position due to changes in either operational pressure or flow rate and given the results of the site testing and CFD modelling (detailed within sections 6, 7 and 8), again there are 3 options for which the determination of the most appropriate estimate of measurement error can be defined;

1. Use all site test results as valid contributions and calculate their average. This option equates to an under-read of 70.688%.

2. Use only those site test results that agree favourably with the CFD modelling results (section 7.6 refers). This option equates to an under-read of 71.608%.

3. Use only those site test results that agree favourably with the CFD modelling results (section 7.6 refers) but in addition only use the result set(s) that align with the flow scenario (low, medium or high) that existed during the SMER Period (i.e. Test 6 – low flow). This option equates to an under-read of 70.554%.

In the opinion of the Appointed Independent Technical Expert, Option 3 is the recommended method for the appropriate SMER Period 2 estimate of measurement error as the following criteria are met;

9.0 CORRECTION FACTOR CALCULATION SUMMARY

A. Only those site test points which agree favourably with the CFD modelling results are used (section 7.6 refers – results of tests 1, 9 & 11 excluded due to the significant discrepancy seen from the CFD modelling results).

B. The site test result(s) that is/are the most representative of the SMER flow rates are used. In this case, as can be seen from figure 5.1.12, all flow was within the low flow band (< 0.8 $MMSm^3$/day) with the exception of an 8 minute reported flow duration (7th August 2010 between 15.04hrs and 15:12hrs) following reinstatement of the metering system on completion of site investigation visit (Fault Log 112402 refers).

It is therefore recommended that the result of Test 6 (70.554%) is used as the basis for the derivation of the estimated correction factor figure;

Correction Factor = $\mathbf{\frac{100}{100 - 70.554} = 3.396}$ (70.554%)

10.0 RECOMMENDATIONS

The recommendation of this review is to multiply each of the daily standard volume totals reported within Gemini (during the SMER periods) as follows;

- For gas day 21st July 2009 (SMER Period 1 commencement date) – this will comprise a part day correction based on the low flow correction factor of 1.335 for flow totals accumulated between 16:03 and 05:59.
- For gas days 22nd July 2009 to 26th July 2010 (SMER Period 1 inclusive) – this will comprise a full day correction using either the low flow correction factor of 1.335 or the mid flow correction factor of 1.382 in accordance with the tabulated data detailed within Appendix A.
- For gas day 27th July 2010 (SMER Period 1 finish date) – this will comprise a part day correction based on the low flow correction factor of 1.335 for flow totals accumulated between 06:00 and 17:22.
- For gas day 27th July 2010 (SMER Period 2 commencement date) this will comprise a part day correction based on the correction factor of 3.396 for flow totals accumulated between 17:23 and 05:59.
- For gas days 28th July 2010 to 09th August 2010 (SMER Period 2 inclusive) this will comprise a full day correction based on the correction factor of 3.396.
- For gas day 10th August 2010 (SMER Period 2 remedial date) this will comprise a part day correction based on based on the correction factor of 3.396 for flow totals accumulated between 06:00 and 13:10.

APPENDIX A

PROPOSED CORRECTION FACTORS APPLICABLE to the DAILY GEMINI TOTALS

APPENDIX A

Date	Proposed GEMINI Daily Correction Factors
21/07/2009	1.335 (16:03 to 05:59)
22/07/2009	1.335
23/07/2009	1.335
24/07/2009	1.335
25/07/2009	1.335
26/07/2009	1.335
27/07/2009	1.335
28/07/2009	1.335
29/07/2009	1.335
30/07/2009	1.335
31/07/2009	1.335
01/08/2009	1.335
02/08/2009	1.335
03/08/2009	1.335
04/08/2009	1.335
05/08/2009	1.335
06/08/2009	1.335
07/08/2009	1.335
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12/08/2009	1.335
13/08/2009	1.335
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18/08/2009	1.335
19/08/2009	1.335
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22/08/2009	1.335
23/08/2009	1.335
24/08/2009	1.335
25/08/2009	1.335
26/08/2009	1.335
27/08/2009	1.335
28/08/2009	1.335
29/08/2009	1.335
30/08/2009	1.335
31/08/2009	1.335
01/09/2009	1.335
02/09/2009	1.335
03/09/2009	1.335
04/09/2009	1.335
05/09/2009	1.335

	06/09/2009	1.335	
	07/09/2009	1.335	
	08/09/2009	1.335	
	09/09/2009	1.335	
	10/09/2009	1.335	
	11/09/2009	1.335	
	12/09/2009	1.335	
	13/09/2009	1.335	
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	15/09/2009	1.335	
	16/09/2009	1.335	
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	29/09/2009	1.382	
	30/09/2009	1.382	
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	28/10/2009	1.382	
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	13/12/2009	1.382	
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	18/05/2010	1.382	
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	27/05/2010	1.382	
	28/05/2010	1.382	
	29/05/2010	1.382	
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	31/05/2010	1.382	
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	01/07/2010	1.335	
	02/07/2010	1.335	

	03/07/2010	1.335	
	04/07/2010	1.335	
	05/07/2010	1.335	
	06/07/2010	1.335	
	07/07/2010	1.335	
	08/07/2010	1.335	
	09/07/2010	1.335	
	10/07/2010	1.335	
	11/07/2010	1.335	
	12/07/2010	1.335	
	13/07/2010	1.335	
	14/07/2010	1.335	
	15/07/2010	1.335	
	16/07/2010	1.335	
	17/07/2010	1.335	
	18/07/2010	1.335	
	19/07/2010	1.335	
	20/07/2010	1.335	
	21/07/2010	1.335	
	22/07/2010	1.335	
	23/07/2010	1.335	
	24/07/2010	1.335	
	25/07/2010	1.335	
	26/07/2010	1.335	
	27/07/2010	1.335 (06:00 to 17.22)	
	27/07/2010	3.396 (17.23 to 05:59)	
	28/07/2010	3.396	
	29/07/2010	3.396	
	30/07/2010	3.396	
	31/07/2010	3.396	
	01/08/2010	3.396	
	02/08/2010	3.396	
	03/08/2010	3.396	
	04/08/2010	3.396	
	05/08/2010	3.396	
	06/08/2010	3.396	
	07/08/2010	3.396	
	08/08/2010	3.396	
	09/08/2010	3.396	
	10/08/2010	3.396 (06:00 to 13:10)	

APPENDIX B

TYPICAL TEST RESULT SPREADSHEET (HIGH FLOW /MID PRESSURE TEST)

KELTON®

APPENDIX B

Time	F1_Day	FLOW_hr	FP1	FT1	HighDP	LowDP	StandbyDP	
15:53:09	4.6651	194.3786	62.0334	10.09	522.0875	Over-range	522.0875	Counter Position 00000 / Flow Stability Period
15:53:19	4.6686	194.5251	62.0334	10.09	519.1577	Over-range	519.2493	
15:53:29	4.6559	193.994	62.0334	10.09	518.1506	Over-range	518.3337	
15:53:39	4.6589	194.1222	62.0334	10.09	519.9817	Over-range	520.2563	
15:53:49	4.6611	194.2138	62.0334	10.09	520.0732	Over-range	519.707	
15:53:59	4.644	193.4996	62.0334	10.09	514.8547	Over-range	514.8547	
15:54:09	4.6497	193.7377	62.0334	10.09	519.0662	Over-range	519.4324	
15:54:19	4.6409	193.3715	62.0334	10.09	514.9462	Over-range	515.2209	
15:54:29	4.6466	193.6095	62.0481	10.09	516.6857	Over-range	517.0519	
15:54:39	4.6431	193.463	62.0334	10.09	517.5097	Over-range	517.1435	
15:54:49	4.6387	193.2799	62.0334	10.09	516.7773	Over-range	517.0519	
15:54:59	4.6405	193.3532	62.0334	10.09	514.58	Over-range	514.4885	
15:55:09	4.6348	193.1151	62.0334	10.09	513.8475	Over-range	514.1223	
15:55:19	4.6251	192.7123	62.0334	10.09	513.4813	Over-range	513.5729	
15:55:29	4.6211	192.5475	62.0334	10.09	512.932	Over-range	512.4742	
15:55:39	4.6211	192.5475	62.0481	10.09	513.8475	Over-range	513.9391	
15:55:49	3.7172	154.8821	62.0554	10.09	319.6613	Over-range	319.5697	
15:55:59	3.4741	144.7562	62.0334	10.09	285.0538	Over-range	285.3285	Counter Position 99985
15:56:09	3.4636	144.3168	62.0334	10.09	285.6947	Over-range	285.9693	
15:56:19	3.4517	143.8224	62.0334	10.09	283.6805	Over-range	283.9552	
15:56:29	3.4443	143.5111	62.0334	10.09	283.1312	Over-range	283.2227	
15:56:39	3.4456	143.566	62.0334	10.09	283.0396	Over-range	283.2227	
15:56:49	3.4447	143.5294	62.0481	10.09	283.1312	Over-range	283.4059	
15:56:59	3.4456	143.566	62.0554	10.09	282.8565	Over-range	282.9481	
15:57:09	3.446	143.5843	62.0554	10.09	282.5818	Over-range	282.8565	
15:57:19	3.4421	143.4196	62.0627	10.09	281.0254	Over-range	281.3001	
15:57:29	3.4399	143.328	62.0554	10.09	282.2156	Over-range	282.5818	
15:57:39	3.4284	142.8519	62.0554	10.09	279.469	Over-range	280.0183	
15:57:49	3.4271	142.797	62.0554	10.09	279.469	Over-range	279.8352	
15:57:59	3.4249	142.7054	62.0554	10.09	278.8282	Over-range	279.469	
15:58:09	3.4306	142.9435	62.0554	10.09	276.8139	Over-range	278.0041	
15:58:19	3.4078	141.9913	62.0554	10.09	276.8139	Over-range	276.9055	Counter Position 99984
15:58:29	3.4122	142.1744	62.0554	10.09	277.4548	Over-range	278.3703	
15:58:39	3.4122	142.1744	62.0554	10.09	275.6237	Over-range	276.1731	
15:58:49	3.3946	141.442	62.0554	10.09	275.99	Over-range	276.1731	
15:58:59	3.3946	141.442	62.0554	10.09	275.5322	Over-range	275.8984	
15:59:09	3.399	141.6251	62.0554	10.09	275.8069	Over-range	276.0815	
15:59:19	3.406	141.918	62.0554	10.09	275.5322	Over-range	275.2575	
15:59:29	3.3999	141.6617	62.0554	10.09	274.8913	Over-range	274.9829	
15:59:39	3.2869	136.9558	62.0554	10.09	251.3619	Over-range	251.3619	
15:59:49	3.0145	125.6031	62.0334	10.09	214.8318	Over-range	215.1064	
15:59:59	2.7943	116.4294	62.0334	10.09	185.0767	Over-range	185.4429	
16:00:09	2.775	115.6237	62.0334	10.09	182.7878	Over-range	182.6047	Counter Position 99970

16:00:19	2.7715	115.4772	62.0334	10.09	182.6047	Over-range	182.9709	
16:00:29	2.7767	115.6969	62.0334	10.09	182.0554	Over-range	182.2385	
16:00:39	2.7802	115.8434	62.0334	10.09	183.978	Over-range	184.4358	
16:00:49	2.7802	115.8434	62.0334	10.09	182.147	Over-range	183.6118	
16:00:59	2.7701	115.4223	62.0334	10.09	182.3301	Over-range	182.2385	
16:01:09	2.7688	115.3674	62.0334	10.09	181.4145	Over-range	182.3301	
16:01:19	2.7618	115.0744	62.0334	10.09	181.4145	Over-range	181.5976	
16:01:29	2.7618	115.0744	62.0334	10.09	179.2172	Over-range	179.675	
16:01:39	2.757	114.873	62.0334	10.09	180.6821	Over-range	181.0483	
16:01:49	2.5174	104.8936	62.0334	10.09	138.3841	Over-range	139.0249	
16:01:59	1.8249	76.0357	62.0114	10.09	73.1975	69.7597	73.3806	
16:02:09	1.4926	62.1927	62.0114	10.09	54.3374	52.7398	54.612	
16:02:19	1.3564	56.5164	62.0114	10.09	44.358	43.5203	44.4495	Counter Position 99950
16:02:29	1.3546	56.4431	62.0188	10.09	43.7171	44.1978	43.9917	
16:02:39	1.3608	56.6995	62.0114	10.09	43.6255	43.447	43.9917	
16:02:49	1.3436	55.9854	62.0114	10.09	43.6255	44.0513	43.9002	
16:02:59	1.3568	56.5347	62.0188	10.09	43.1678	42.7695	43.4424	
16:03:09	1.3498	56.2417	62.0334	10.09	43.9002	41.7533	44.0833	
16:03:19	1.352	56.3333	62.0188	10.09	43.7171	42.5498	43.9002	
16:03:29	1.352	56.3333	62.0261	10.09	43.4424	41.6068	43.7171	
16:03:39	1.3533	56.3882	62.0334	10.09	43.6255	42.1744	43.9917	
16:03:49	1.3485	56.1868	62.0334	10.09	42.8931	42.3301	43.1678	
16:03:59	1.3406	55.8572	62.0334	10.09	42.9847	43.4562	43.2593	
16:04:09	1.345	56.0403	62.0334	10.09	42.8931	41.5702	43.2593	
16:04:19	1.352	56.3333	62.0334	10.09	43.534	43.0442	43.9002	
16:04:29	0.884	36.8322	62.0334	10.09	19.3637	14.7814	19.7299	
16:04:39	0.4353	18.1369	62.0627	10.09	5.539	3.6484	5.9052	Counter Position 99885 / Fully Racked Out
16:04:49	0.3382	14.0902	62.0627	10.09	3.1586	2.5406	3.3417	
16:04:59	0.3232	13.4676	62.0627	10.09	2.9755	2.2477	3.3417	
16:05:09	0.3241	13.5042	62.0627	10.09	2.9755	2.2934	3.3417	
16:05:19	0.3237	13.4859	62.0627	10.09	2.9755	2.385	3.2502	
16:05:29	0.321	13.3761	62.0627	10.09	2.9755	2.2568	3.2502	
16:05:39	0.3276	13.6507	62.0627	10.09	2.9755	2.5223	3.3417	
16:05:49	0.3193	13.3028	62.0627	10.09	2.9755	2.1286	3.2502	
16:05:59	0.3193	13.3028	62.0627	10.09	2.884	2.3209	3.0671	
16:06:09	0.3245	13.5225	62.0627	10.09	2.9755	2.3941	3.2502	
16:06:19	0.3136	13.0648	62.0627	10.09	2.884	2.2293	3.0671	
16:06:29	0.3254	13.5592	62.0554	10.09	2.9755	2.3392	3.2502	
16:06:39	0.3298	13.7423	62.0627	10.09	2.9755	2.2568	3.2502	
16:06:49	0.3281	13.669	62.0627	10.09	2.9755	2.5132	3.3417	
16:06:59	0.2894	12.0577	62.0627	10.09	2.2431	2.1012	2.6093	
16:07:09	0.6682	27.8416	62.0627	10.09	10.8492	11.2108	11.3069	
16:07:19	0.924	38.4985	62.0627	10.09	20.3708	20.6409	20.6455	
16:07:29	1.0962	45.6764	62.0481	10.09	28.1529	28.0201	28.4276	
16:07:39	1.1837	49.3202	62.0334	10.09	33.5546	33.2937	33.7377	

16:07:49	1.2751	53.1289	62.0334	10.09	38.5901	37.3587	38.9563	Counter Position 99950	
16:07:59	1.2637	52.6528	62.0334	10.09	38.1323	37.2854	38.407		
16:08:09	1.2571	52.3781	62.0334	10.09	37.9492	37.0474	38.3154		
16:08:19	1.258	52.4147	62.0334	10.09	38.0407	36.7636	38.407		
16:08:29	1.2645	52.6894	62.0334	10.09	38.0407	38.0087	38.407		
16:08:39	1.2558	52.3232	62.0334	10.09	37.9492	36.8002	38.2238		
16:08:49	1.2606	52.5246	62.0334	10.09	37.4914	36.9924	37.8576		
16:08:59	1.2711	52.9641	62.0334	10.09	38.4985	36.8551	38.8647		
16:09:09	1.2593	52.4697	62.0334	10.09	37.8576	36.6079	38.0407		
16:09:19	1.2496	52.0668	62.0334	10.09	37.583	37.5418	37.9492		
16:09:29	1.2562	52.3415	62.0481	10.09	37.583	38.1277	37.8576		
16:09:39	1.2588	52.4514	62.0334	10.09	38.0407	36.7544	38.3154		
16:09:49	1.7427	72.6116	62.0627	10.09	79.057	81.1032	79.3316		
16:09:59	2.3122	96.3424	62.0627	10.09	128.7709	Over-range	129.5949		
16:10:09	2.426	101.0849	62.0627	10.09	140.3067	Over-range	140.7645	Counter Position 99970	Flow Instability Noted
16:10:19	2.4375	101.561	62.0627	10.09	140.856	Over-range	141.1307		
16:10:29	2.4423	101.7624	62.0627	10.09	140.3983	Over-range	140.856		
16:10:39	2.4432	101.799	62.0627	10.09	141.4969	Over-range	141.5885		
16:10:49	2.4405	101.6892	62.0627	10.09	140.9476	Over-range	141.2222		
16:10:59	2.4379	101.5793	62.0627	10.09	140.3983	Over-range	140.6729		
16:11:09	2.4361	101.5061	62.0627	10.09	141.2222	Over-range	141.4969		
16:11:19	2.4344	101.4328	62.0627	10.09	139.6658	Over-range	139.8489		
16:11:29	2.4348	101.4511	62.0627	10.09	139.0249	Over-range	139.8489		
16:11:39	2.4313	101.3046	62.0627	10.09	139.1165	Over-range	139.5743		
16:11:49	2.4344	101.4328	62.0627	10.09	139.6658	Over-range	140.0321		
16:11:59	2.4388	101.6159	62.0627	10.09	140.1236	Over-range	140.4898		
16:12:09	2.4304	101.268	62.0627	10.09	139.5743	Over-range	139.6658		
16:12:19	2.4304	101.268	62.07	10.09	139.9405	Over-range	140.3067		
16:12:29	2.9499	122.9114	62.0993	10.09	211.5358	Over-range	212.1767		
16:12:39	3.1349	130.6203	62.0993	10.09	234.699	Over-range	235.3399		
16:12:49	3.192	133.0007	62.0993	10.09	240.5585	Over-range	240.3754	Counter Position 99984	
16:12:59	3.1819	132.5795	62.0993	10.09	239.5514	Over-range	240.0092		
16:13:09	3.1714	132.1401	62.0993	10.09	239.5514	Over-range	240.0092		
16:13:19	3.1806	132.5246	62.0993	10.09	239.2767	Over-range	239.1852		
16:13:29	3.1586	131.6091	62.0993	10.09	235.8892	Over-range	236.0723		
16:13:39	3.1832	132.6345	62.0993	10.09	238.9105	Over-range	239.1852		
16:13:49	3.1705	132.1035	62.0993	10.09	237.0794	Over-range	237.3541		
16:13:59	3.17	132.0851	62.0993	10.09	238.5443	Over-range	238.819		
16:14:09	3.1538	131.4076	62.0993	10.09	235.6145	Over-range	235.7061		
16:14:19	3.1507	131.2794	62.0993	10.09	236.5301	Over-range	236.8963		
16:14:29	3.1749	132.2866	62.0993	10.09	237.4456	Over-range	237.8119		
16:14:39	3.167	131.957	62.0993	10.09	238.5443	Over-range	238.7274		
16:14:49	3.1665	131.9386	62.0993	10.09	236.9879	Over-range	237.3541		
16:14:59	3.1973	133.2204	62.1213	10.09	242.9389	Over-range	243.3967	Counter Position 99985	
16:15:09	3.1925	133.019	62.0993	10.09	241.6571	Over-range	242.7558		
16:15:19	3.21	133.7514	62.1286	10.09	243.2135	Over-range	243.4882		

16:15:29	3.2175	134.0627	62.1286	10.09	243.122	Over-range	243.7629	
16:15:39	3.203	133.4585	62.1286	10.09	243.7629	Over-range	244.1291	
16:15:49	3.203	133.4585	62.1286	10.09	243.6713	Over-range	243.8544	
16:15:59	3.1999	133.3303	62.1286	10.09	242.3896	Over-range	242.5727	
16:16:09	3.1907	132.9457	62.1286	10.09	242.1149	Over-range	242.0234	
16:16:19	3.1911	132.9641	62.1286	10.09	244.6784	Over-range	244.9531	
16:16:29	3.1925	133.019	62.1286	10.09	242.8473	Over-range	243.0304	
16:16:39	3.1911	132.9641	62.1286	10.09	241.2909	Over-range	241.5656	
16:16:49	3.3282	138.677	62.1213	10.09	274.2504	Over-range	274.3419	
16:16:59	4.2929	178.8693	62.1213	10.09	442.5269	Over-range	443.0763	
16:17:09	4.3175	179.8947	62.1213	10.09	443.8087	Over-range	444.0833	
16:17:19	4.3043	179.3454	62.1213	10.09	443.6256	Over-range	443.9002	
16:17:29	4.3078	179.4919	62.1286	10.09	442.2523	Over-range	442.7101	
16:17:39	4.3025	179.2721	62.1213	10.09	443.1678	Over-range	443.2594	
16:17:49	4.2986	179.1073	62.1213	10.09	440.4212	Over-range	440.6958	
16:17:59	4.2929	178.8693	62.1286	10.09	441.4283	Over-range	441.6114	
16:18:09	4.2968	179.0341	62.1213	10.09	440.6043	Over-range	440.6958	
16:18:19	4.2898	178.7411	62.1213	10.09	439.5056	Over-range	439.9634	
16:18:29	4.2832	178.4665	62.1213	10.09	439.9634	Over-range	439.4141	
16:18:39	4.2942	178.9242	62.1286	10.09	437.7661	Over-range	438.9563	
16:18:49	4.2893	178.7228	62.1213	10.09	439.4141	Over-range	439.6888	
16:19:00	4.3003	179.1806	62.1286	10.09	438.4986	Over-range	438.5901	
16:19:10	4.285	178.5397	62.1286	10.09	438.0407	Over-range	438.9563	
16:19:20	4.2797	178.32	62.1286	10.09	438.0407	Over-range	439.0479	
16:19:30	4.2775	178.2284	62.1286	10.09	437.9492	Over-range	438.2239	
16:19:40	4.2748	178.1185	62.1286	10.09	435.7519	Over-range	436.1181	
16:19:50	4.2748	178.1185	62.1286	10.09	437.1252	Over-range	436.8506	
16:20:00	4.2726	178.027	62.1286	10.09	435.2026	Over-range	435.8435	
16:20:10	4.2718	177.9904	62.1433	10.09	436.3928	Over-range	436.6674	
16:20:20	4.2775	178.2284	62.1286	10.09	436.1181	Over-range	436.5759	
16:20:30	4.3693	182.0554	62.1213	10.09	468.3452	Over-range	466.8803	
16:20:40	4.4563	185.6809	62.0993	10.09	479.1486	Over-range	479.5148	
16:20:50	4.4994	187.4754	62.0993	10.09	484.6418	Over-range	485.5573	
16:21:00	4.5196	188.3177	62.0993	10.09	490.776	Over-range	491.1422	
16:21:10	4.5614	190.0572	62.0993	10.09	502.3118	Over-range	501.3047	Counter Position 00000 / Return to Flow Stability Period
16:21:20	4.593	191.3756	62.0993	10.09	504.7837	Over-range	504.8753	
16:21:30	4.5939	191.4122	62.0993	10.09	508.1712	Over-range	507.9881	
16:21:40	4.5992	191.632	62.0993	10.09	508.5374	Over-range	508.4459	
16:21:50	4.6049	191.87	62.0993	10.09	508.7206	Over-range	507.4388	
16:22:00	4.6163	192.3461	62.0993	10.09	511.4672	Over-range	511.1925	
16:22:10	4.6036	191.8151	62.0993	10.09	508.3543	Over-range	507.9881	
16:22:20	4.6189	192.4559	62.0993	10.09	511.6503	Over-range	511.2841	
16:22:30	4.611	192.1263	62.0993	10.09	510.9179	Over-range	510.6432	
16:22:40	4.622	192.5841	62.0993	10.09	512.2911	Over-range	512.5658	
16:22:50	4.629	192.8771	62.0993	10.09	513.4813	Over-range	513.5729	
16:23:00	4.6242	192.6757	62.0993	10.09	512.4742	Over-range	513.2067	

APPENDIX B

16:23:10	4.6102	192.0897	62.0993	10.09	510.277	Over-range	510.4601
16:23:20	4.622	192.5841	62.0993	10.09	511.4672	Over-range	511.8334
16:23:30	4.6176	192.401	62.0993	10.09	512.6573	Over-range	512.4742
16:23:40	4.6154	192.3094	62.0993	10.09	512.1996	Over-range	512.1996
16:23:50	4.6097	192.0714	62.0993	10.09	507.9881	Over-range	508.9037
16:24:00	4.6106	192.108	62.0993	10.09	509.9107	Over-range	508.9952
16:24:10	4.6128	192.1996	62.0993	10.09	509.1783	Over-range	509.453
16:24:20	4.6141	192.2545	62.0993	10.09	510.9179	Over-range	510.8263
16:24:30	4.6163	192.3461	62.0993	10.09	512.2911	Over-range	511.8334
16:24:40	4.6167	192.3644	62.0993	10.09	511.7419	Over-range	512.3827
16:24:50	4.6141	192.2545	62.0993	10.09	509.5445	Over-range	509.7276
16:25:00	4.6141	192.2545	62.0993	10.09	512.1996	Over-range	512.1996
16:25:10	4.6097	192.0714	62.0993	10.09	509.7276	Over-range	510.7348
16:25:20	4.6106	192.108	62.0993	10.09	510.9179	Over-range	511.1925
16:25:30	4.6167	192.3644	62.0993	10.09	512.1996	Over-range	512.932
16:25:40	4.6053	191.8883	62.0993	10.09	507.805	Over-range	507.4388
16:25:50	4.6172	192.3827	62.0993	10.09	510.0939	Over-range	510.1855
16:26:00	4.6176	192.401	62.0993	10.09	510.277	Over-range	510.1855
16:26:10	4.6071	191.9615	62.0993	10.09	510.7348	Over-range	510.8263
16:26:20	4.611	192.1263	62.0993	10.09	511.101	Over-range	511.4672
16:26:30	4.608	191.9982	62.1213	10.09	508.8121	Over-range	508.9037

APPENDIX C

FMC SITE MEASUREMENT REPORT

APPENDIX C

FMC Ltd

Flow Metering Company Ltd - 6 Baird Way, Thetford, Norfolk IP24 1JA
Phone: +44 (0) 1842-822900 - Fax: +44 (0) 1842-765402 Email: sales@fmcltd.uk.com - Website: www.fmcltd.uk.com

FMC Ltd.
6 Baird Way, Thetford
Norfolk, IP24 1JA, England
Phone 01842 822907
Fax 01842 765402
Email: stephen.carpenter@fmcltd.uk.com

Site Visit – Aberdeen Offtake.

Date : 30.11.2011
Customer ref: ?.
FMC Ref :?.
Equipment : 10" Measuremaster.
Contact : Trevor Roberts.

Purpose of visit

To measure the orifice plate position at set points.

The orifice plate had been found to not be in the correct position during a previous inspection. This exercise to to check the actual orifice position against the counter readings.
Table 1 shows the measurements taken of the orifice plate position with as found reading at 00001 moving the orifice plate out of the down position and recording in various stages.
Table 2 shows the orifice plate position after extracting the orifice plate out of position and free from the sealing areas, plate was cleaned before reinserting. Please note the offset measurement B changes to a – when moving the plate down.
Table 3 shows the check positions of the orifice plate, each check was done after full extraction of the plate and lowering into place.

Temperature recordings taken;
Table 1 at 6.0 Deg C
Table 2 at 6.0 Deg C
Table 3 at 7.3 Deg C

Measured using Metric Slips Serial number TESA 16899.
Calibrated 26th March 2009 (calibrate every three years).

Provider of Orifice Fittings and Venturi Meters for oil and gas applications previously sold by:

FMC Technologies Inc.

APPENDIX B

FMC Ltd

Flow Metering Company Ltd - 6 Baird Way, Thetford, Norfolk IP24 1JA
Phone: +44 (0) 1842-822900 - Fax: +44 (0) 1842-765402 Email: sales@fmcltd.uk.com - Website: www.fmcltd.uk.com

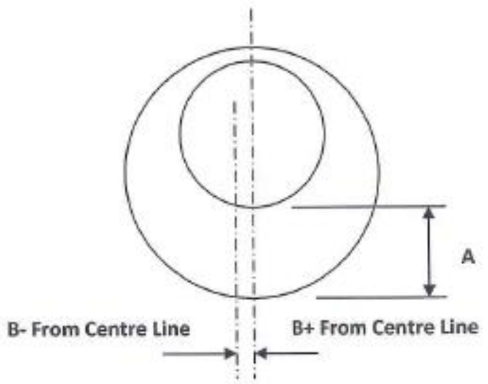

Table 1 – Gives position of plate moving upwards against counter reading.

Counter Reading	A Position	B+ Position
00001	39.0	0.0
99995	50.4	0.0
99984	88.7	11.5
99970	137.9	17.5
99960	174.0	24.5
99950	209.8	22.5
99940	244.0	14.5

Table 2 – Gives position of the orifice plate moving downwards against the counter reading.

Counter Reading	A Position	B- Position
99940	245.5	22.5
99950	210.5	22.5
99960	175.0	26.5
99970	139.1	25.5
99984	90.8	19.5
99995	52.5	0.0
00000	39.0	0.0

APPENDIX B

FMC Ltd

Flow Metering Company Ltd - 6 Baird Way, Thetford, Norfolk IP24 1JA
Phone: +44 (0) 1842-822900 - Fax: +44 (0) 1842-765402 Email: sales@fmcltd.uk.com - Website: www.fmcltd.uk.com

Table 3 – Check positions.

Counter Reading	A Position	B- Position
99950	210.5	22.5
99984	90.5	18.6
99950	210.5	22.5
99984	90.8	19.5

FMC LTD

Stephen Carpenter
QA Manager
30/11/2011

Provider of Orifice Fittings and Venturi Meters for oil and gas applications previously sold by:

FMC Technologies Inc.

APPENDIX D

ORIFICE PLATE INSPECTION "AS FOUND" PHOTOGRAPHS

APPENDIX D

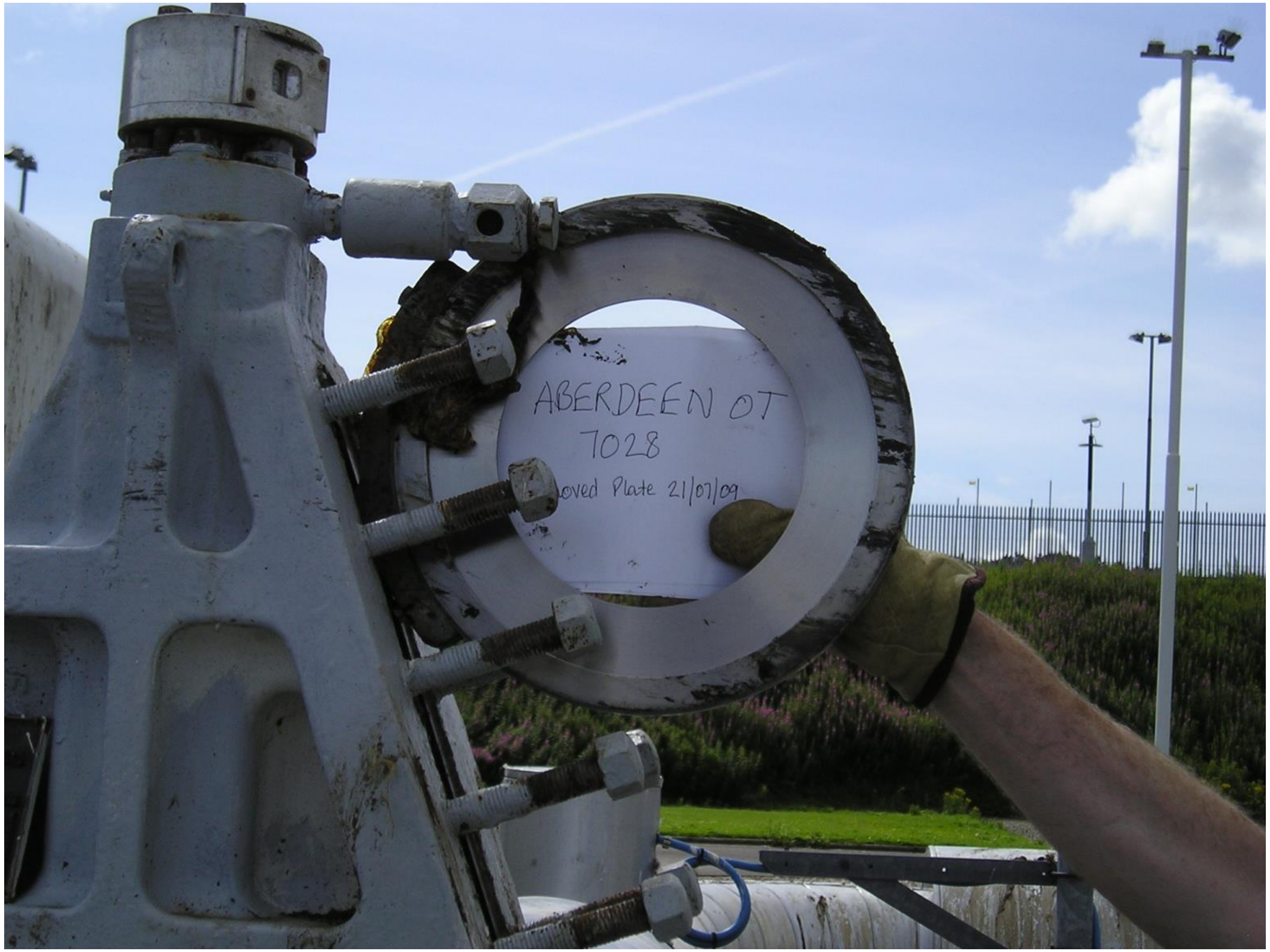

Figure D.1 – Orifice Plate ("As Found") 21st July 2009

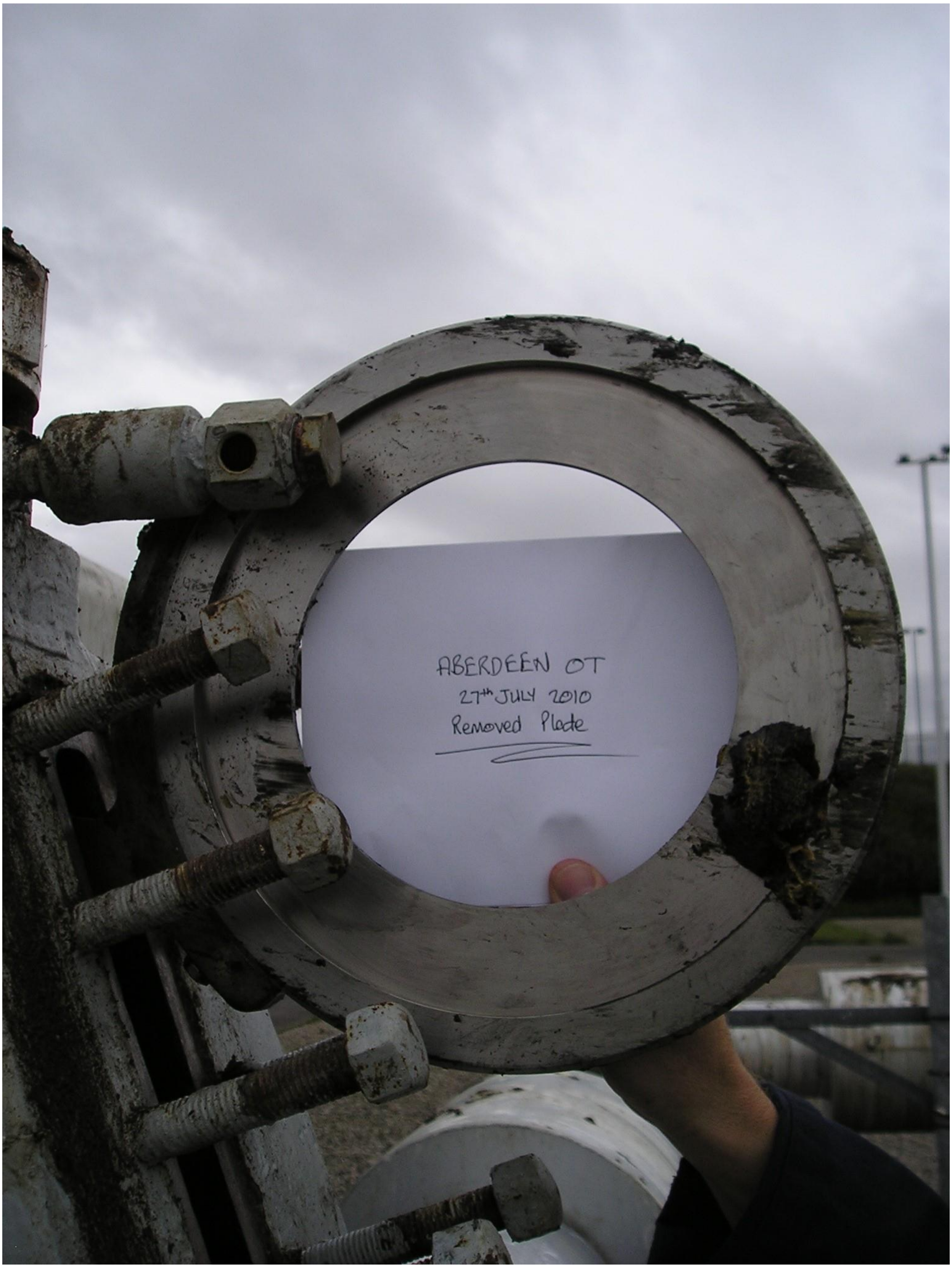

Figure D.2 – Orifice Plate ("As Found") 27th July 2010

APPENDIX E

SMER PERIOD 1 – AVERAGE DAILY FLOW BANDS

APPENDIX E

Date	In-the-Day Flow Band			End-of-Day GEMINI Band
	Low	Medium	High	
21/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
22/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
23/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
24/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
25/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
26/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
27/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
28/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
29/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
30/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
31/07/2009	✓			Low Flow (> 0.8 MMSm^3/d
01/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
02/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
03/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
04/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
05/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
06/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
07/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
08/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
09/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
10/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
11/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
12/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
13/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
14/08/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
15/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
16/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
17/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
18/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
19/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
20/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
21/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
22/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
23/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
24/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
25/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
26/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
27/08/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
28/08/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
29/08/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
30/08/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
31/08/2009	✓			Low Flow (> 0.8 MMSm^3/d
01/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
02/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
03/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
04/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d
05/09/2009	✓			Low Flow (> 0.8 MMSm^3/d

	06/09/2009	✓			Low Flow (> 0.8 MMSm^3/d	
	07/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	08/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	09/09/2009	✓			Low Flow (> 0.8 MMSm^3/d	
	10/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	11/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	12/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	13/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	14/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	15/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	16/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	17/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	18/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	19/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	20/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	21/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	22/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	23/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	24/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	25/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	26/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	27/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	28/09/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	29/09/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/09/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/10/2009	✓	✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/10/2009	✓	✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	

APPENDIX E

	26/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/10/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	31/10/2009	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	01/11/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/11/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/11/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/11/2009		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/11/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/11/2009	✓	✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/11/2009		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/11/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/12/2009		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	

APPENDIX E

	15/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/12/2009	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/12/2009		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/12/2009		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/12/2009		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	31/12/2009		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/01/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	31/01/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	

	03/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/02/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/02/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/03/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/03/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	

APPENDIX E

	25/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/03/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	31/03/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/04/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/04/2010		✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	16/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	20/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	21/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	22/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	23/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	24/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/04/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/04/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	02/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	03/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	04/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	05/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	06/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	07/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	08/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/05/2010	✓	✓	✓	Medium Flow (0.8 - 2.2 MMSm^3/d	
	12/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	

APPENDIX E

	14/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	16/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	17/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	18/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	19/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	20/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	21/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	22/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	23/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	24/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	25/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	26/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	27/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	28/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	29/05/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	30/05/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	31/05/2010		✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	01/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	02/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	03/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	04/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	05/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	06/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	07/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	08/06/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	09/06/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	10/06/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	11/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	12/06/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	13/06/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	14/06/2010	✓	✓		Medium Flow (0.8 - 2.2 MMSm^3/d	
	15/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	16/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	17/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	18/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	19/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	20/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	21/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	22/06/2010		✓		Low Flow (> 0.8 MMSm^3/d	
	23/06/2010		✓		Low Flow (> 0.8 MMSm^3/d	
	24/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	25/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	26/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	27/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	28/06/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	
	29/06/2010	✓			Low Flow (> 0.8 MMSm^3/d	
	30/06/2010	✓			Low Flow (> 0.8 MMSm^3/d	
	01/07/2010	✓			Low Flow (> 0.8 MMSm^3/d	
	02/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d	

APPENDIX E

03/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
04/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
05/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
06/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
07/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
08/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
09/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
10/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
11/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
12/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
13/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
14/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
15/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
16/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
17/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
18/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
19/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
20/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
21/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
22/07/2010	✓	✓		Low Flow (> 0.8 MMSm^3/d
23/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
24/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
25/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
26/07/2010	✓			Low Flow (> 0.8 MMSm^3/d
27/07/2010	✓			Low Flow (> 0.8 MMSm^3/d