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Project Title	**:**	**BRAISHFIELD "B" MEASUREMENT ERROR REVIEW**
Document Title	**:**	**INDEPENDENT EXPERT SIGNIFICANT METER ERROR (SMER) - INTERIM REPORT**
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1.0 INTRODUCTION

This report details the work carried out (to date) by the Appointed Independent Technical Expert (Keith Vugler of KELTON®) to complete a technical evaluation of a Significant Meter Error Report (SMER) raised by Southern Gas Networks (SGN) on their Braishfield "B" metering facility in Hampshire, England.

This SMER has been allocated a unique reference number by the Joint Office of Gas Transporters, SO001

In accordance with the "Measurement Error Notification Guidelines for NTS to LDZ Measurement Installations" document V2, 16/10/08, the final SMER technical evaluation report will incorporate the requirements of section 10 (Generic Terms for an Appointed Independent Technical Expert) and additionally the requirements of section 14 (Business Rules for the Compilation of a SMER).

The final report deliverables are therefore interpreted as follows;

- 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
- Review of all technical SMER issues
- Define the magnitude of the SMER for every day during the period on a Standard Volume basis and clearly identifying whether it's an over or under registration

The final report will be issued once the completion of all site tests has been completed and the results have been appropriately evaluated.

2.0 EXECUTIVE SUMMARY

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

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 Braishfield "B" 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 Independent Expert as the most appropriate technical methodology.

A site test procedure was developed (section 5.4 refers) and initially implemented at site on 2nd August 2010. Whilst the results of these initial flow tests produced results that were "very similar" (within ±0.4%) over the different flow ranges seen during the SMER period (but limited to a pressure change of typically 1 Barg (54.45 to 53.36), it could not be definitively confirmed whether the small fall in operating pressure during the testing period contributed to the small change in error results or that it was more a function of the inherent uncertainty of the test environment.

Whilst section 6.0 of this report demonstrates that pressure differences within the meter stream would produce only a second order effect, it is unclear at this point of the SMER review if pressure differences will have an effect on the manifold equalising valve characteristics.

For this reason, additional tests are required to be performed at a significantly different pressure (typically 10 Barg) to ensure that any "shift" in the error results (section 7 refers) can be clearly attributed to a change in manifold equalising valve characteristics or indeed that "the spread" of error results are a function of the reproducibility of the test environment uncertainty. It is understood these additional tests are scheduled for late October 2010.

Initial indications (supported from site test data – section 7 refers) are that the flow error(s) during the SMER period typically equate to an under-read of 42%.

If it is shown from further testing that meter stream operating pressure has no significant effect on the flow rate errors seen to date, a "single" correction factor can be calculated (as part of this review) which can be applied to all flow rates recorded during the SMER period.

However, if it is confirmed that pressure changes have an "identifiable" effect on the manifold equalising valve characteristics, thoughts at this interim stage are that "several" correction factors will need to be calculated to apply to different pressure "bands" across the flow rate(s) recorded during the SMER period.

The following "Significant Meter Error Notification" was first raised on 12/05/10;

Measurement Error Notification			
Unique Reference Number (Allocated by Joint Office)			
Error Status	Error Notified		
Brief Description	Differential pressure transmitter equalising valve open		
Reason Measurement Error Detected	System Operator linepack checks		
Process Dates	**Latest Notification Update**	12/05/2010	
	Anticipated MER/SMER Publication	12/11/2010	
Measurement Error Dates	**First Notified**	12/05/2010	
	Discovered	26/04/2010	
	Started (or last good read)	26/01/2010	
	Corrected	26/04/2010	
Offtake		Braishfield B MTB	BRABOF
Transporter	**Upstream**	National Grid - NTS	
	Downstream	Scotia Gas - DN	
Meter Type		Orifice	
LDZ		SO	
Average flow rates for the meter for the perceived duration of the Measurement Error (MCM/Day)		2.85	
Assessed volume of error (MCM)		107	
Estimated quantity of error (GWh)		1161	
Estimated Significance		High	>= 50 GWh
Systematic Bias?		Yes	
Over or Under Read?		Under	

Figure 3.1 – Measurement Error Notification

The principal cause of the Braishfield "B" SMER has been identified as being the result of an OPEN equalising valve on the common differential pressure transmitter (ΔP) isolation manifold.

It has transpired that following a visit on the **26th January 2010** to change-out the low range ΔP transmitter that had previously failed a routine ME2 check, the isolation manifold equalising value was left open on completion of the change-out activity.

The chart extract from the incident report (3.2 over page) supports the start date and time of the measurement error.

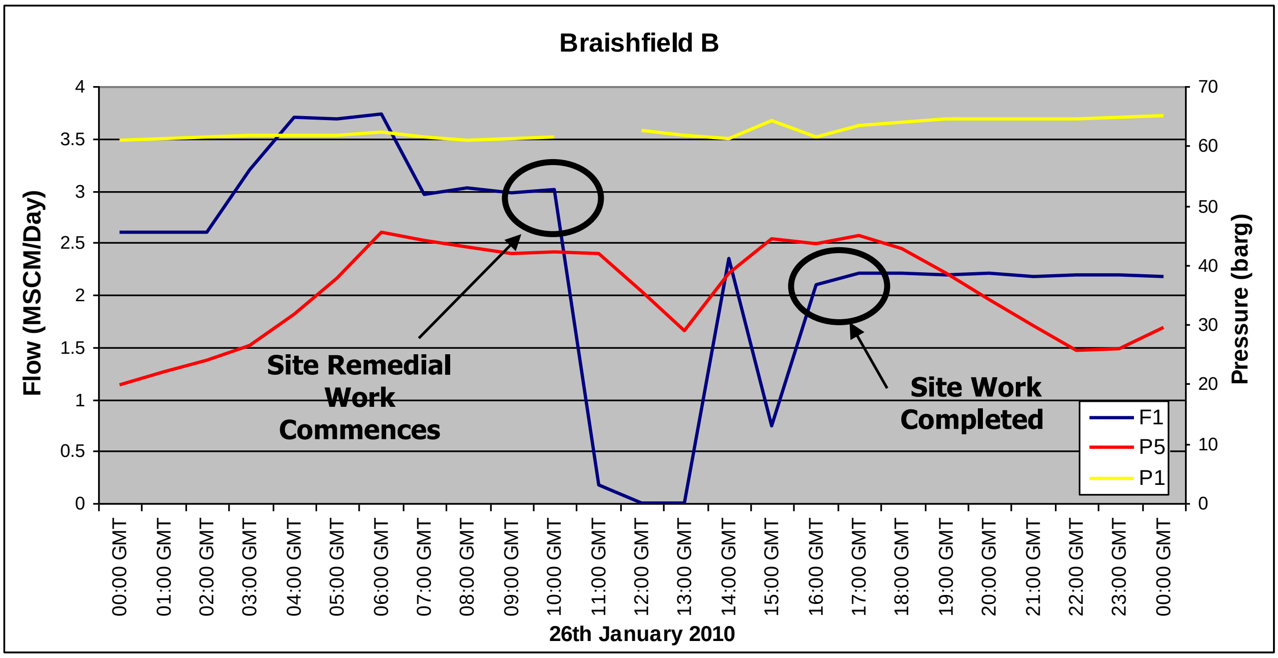
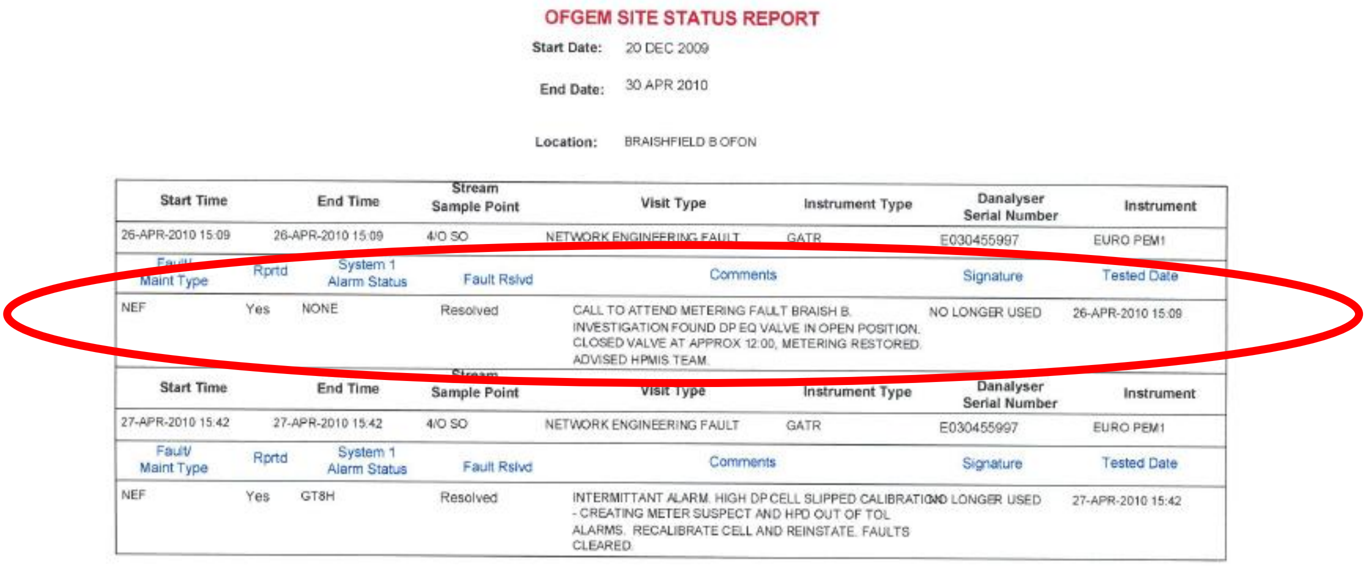


Figure 3.2 – Braishfield "B" Operating Data for 26/01/2010

The equalising value fault was identified on **26th April 2010** supported by the following statement of the C&I Technician attending site; *On the 26th April 2010, I was made aware of the metering issue by Richard Keat and went to site to investigate, suspecting a configuration error of sorts. It was then I found the equaliser valve in the fully open position. I closed the valve and asked System Control to recheck the metering calculations and they confirmed the metering errors had cleared. I advised Richard Keat of what I found and he contacted Network Integrity to notify the metering error and to begin the investigation process.*



OFGEM SITE STATUS REPORT

Start Date: 20 DEC 2009

End Date: 30 APR 2010

Location: BRAISHFIELD B OFON

Start Time	End Time	Stream Sample Point	Visit Type	Instrument Type	Danalyser Serial Number	Instrument
26-APR-2010 15:09	26-APR-2010 15:09	4/O SO	NETWORK ENGINEERING FAULT	GATR	E030455997	EURO PEM1

Fault/ Maint Type	Rprtd	System 1 Alarm Status	Fault Rslvd	Comments	Signature	Tested Date
NEF	Yes	NONE	Resolved	CALL TO ATTEND METERING FAULT BRAISH B. INVESTIGATION FOUND DP EQ VALVE IN OPEN POSITION. CLOSED VALVE AT APPROX 12:00, METERING RESTORED. ADVISED HPMIS TEAM.	NO LONGER USED	26-APR-2010 15:09

Start Time	End Time	Stream Sample Point	Visit Type	Instrument Type	Danalyser Serial Number	Instrument
27-APR-2010 15:42	27-APR-2010 15:42	4/O SO	NETWORK ENGINEERING FAULT	GATR	E030455997	EURO PEM1

Fault/ Maint Type	Rprtd	System 1 Alarm Status	Fault Rslvd	Comments	Signature	Tested Date
NEF	Yes	GT8H	Resolved	INTERMITTANT ALARM. HIGH DP CELL SLIPPED CALIBRATION - CREATING METER SUSPECT AND HPD OUT OF TOL ALARMS. RECALIBRATE CELL AND REINSTATE. FAULTS CLEARED.	NO LONGER USED	27-APR-2010 15:42

Figure 3.3 – Braishfield "B" Site Log for 26/04/2010

From the information shown within Figures 3.2 and 3.3, the period of the SMER can be confirmed as;

- **Start – 10:00 hrs on 26th January 2010**
- **Finish – 12:00 hrs on 26th April 2010**

As previously stated, the principal cause of the Braishfield "B" SMER has been identified as being the result of an OPEN equalising valve on the common differential pressure transmitter (ΔP) isolation manifold. The manifold design is shown below;

Figure 3.4 – Common ΔP Isolation Manifold

Figure 4.1 – Site Layout

4.0 SYSTEM DESCRIPTION

The Braishfield "B" metering system comprises a single 12" meter run fitted with a Daniel Junior (single chamber) orifice fitting.

Figure 4.2 – Daniel Orifice Fitting

The meter run has a total upstream straight length of approximately 57 pipe diameters (D) after which the pipe goes underground by means of a 45° bend. 41D upstream of the orifice fitting is a full bore inlet isolation valve.

Figure 4.3 – Upstream Pipe Section

Figure 4.4 – Upstream Pipe Section Inlet

Figure 4.5 – Normally Buried Inlet Section

Immediately downstream of the orifice fitting there is a flanged section of straight pipe approximately 6D long. 4D downstream of the flange the pipe goes underground by means of a 45^{o} bend.

A 4-wire RTD temperature element is installed in an insertion pocket approximately 7D downstream of the primary device, downstream of the flanged section of pipe.

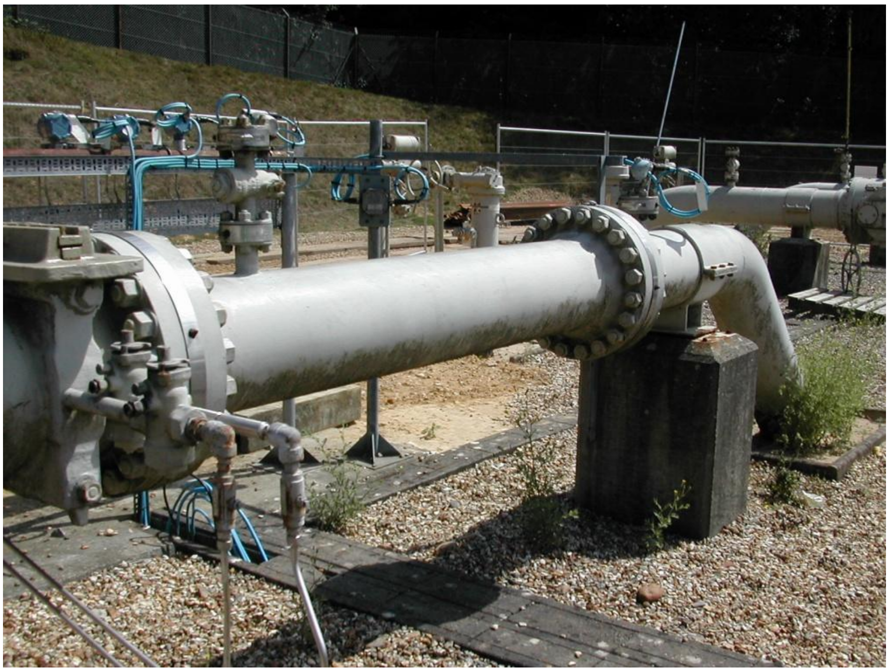


Figure 4.6 – Downstream Pipe Section

The upstream and downstream straight lengths, including the orifice fitting and temperature flange are not insulated. An orifice plate with β = 0.639 was installed at the time of the site visit.

There is a nominal 450 mm diameter underground by-pass line common to the Braishfield A and B meter runs with an isolation valve at each end. Both of the by-pass valves were closed and the upstream valve actuator had been sealed on behalf of OFGEM.

Differential pressure (ΔP) is measured by two high range and a single low range transmitter (calibrated 0-500 and 0-50 mbar respectively). The high range ΔP transmitters are operated in duty/standby mode. The high (duty) transmitter is a Rosemount type 1151, the high (standby) transmitter is a Rosemount type 3051 and the low transmitter is a Rosemount type 1151. The ΔP transmitters are isolated with a single 5-valve manifold with a single equalising valve. A Honeywell ST 170G pressure transmitter is used to measure line pressure.

The pressure impulse lines are installed with a fall from the orifice fitting tappings and the transmitters to catchpots fitted with drain valves. The lines are not insulated.

Figure 4.7 – Transmitter Mounting Rack

Figure 4.8 – Transmitter Impulse Lines and Catchpots

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

Figure 4.9 – Metering Panel

Sample gas is taken from an underground tapping point and the needle valve was sealed open with a seal on behalf of OFGEM. It could not be ascertained if a sample probe is fitted but it is unlikely.

The sample gas is conditioned using a two stage pressure letdown system, (58 - 10 – 2.65 barg at the time of the visit) installed within a dedicated enclosure approximately 4m from the sample take-off, the first stage of which is with dual, parallel base heated regulators. The sample line is routed from the cabinet to a nearby Daniel Series 500 on-line gas chromatograph (OGC). There was insulation on most of the sample line but the ends were not insulated.

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 SGN control at Horley 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 in Havant 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.

5.0 TECHNICAL METHODOLOGY

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 Braishfield "B" 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 seen throughout the SMER period were derived (the x-axis representing the number of data points collected during the SMER);

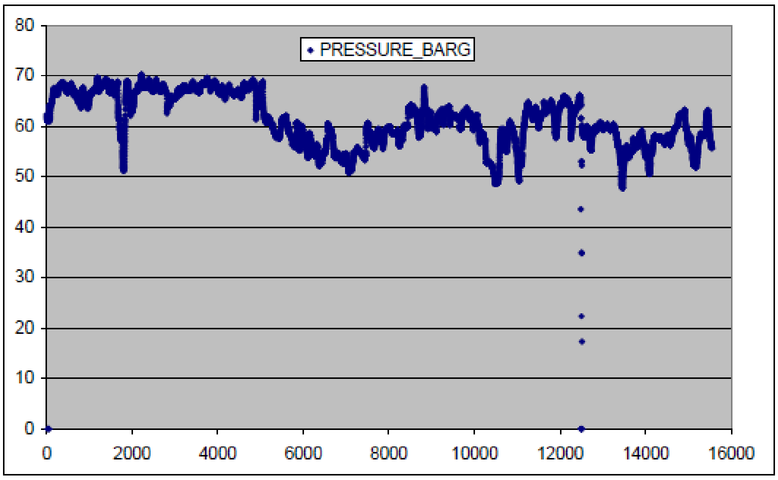


Figure 5.1 – SMER Period Pressure Change

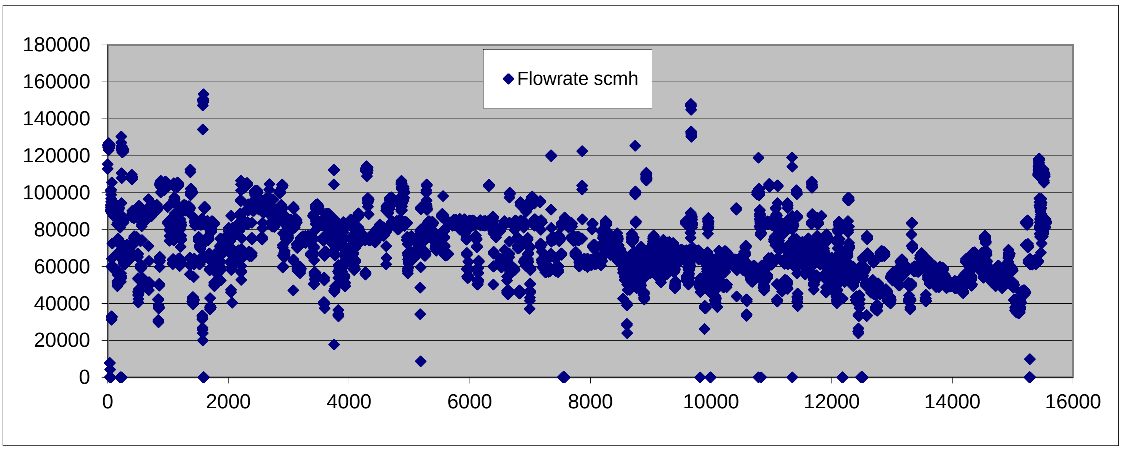


Figure 5.2 – SMER Period Flow Rate Change

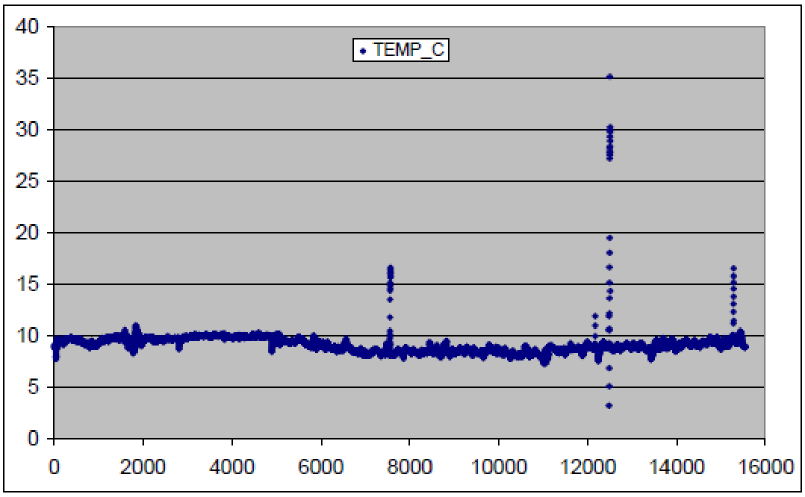


Figure 5.3 – SMER Period Temperature Change

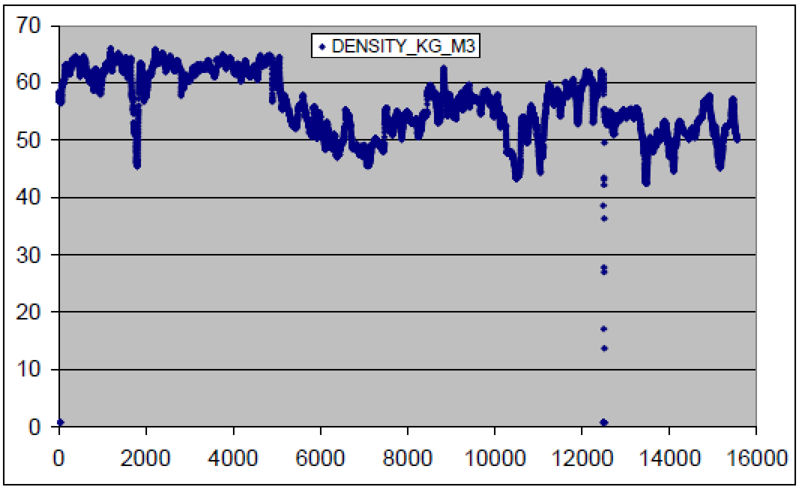


Figure 5.4 – SMER Period Density Change

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

- Pressure 50 – 70 BarG
- Flow Rate 40 – 100 KSm^3/h
- Temperature 7 – 10ºC
- Density 42 – 65 kg/ m^3

Unfortunately, only pressure and flow rate can be controlled during a site test of this nature. However, if it can be demonstrated that these are actually the only two primary operating parameters (or even just one of them) that need to be considered, then the validity of site testing can be deemed representative.

The effects of varying operational conditions in **only** two areas need to be considered in detail for the technical evaluation of this SMER;

- The Meter Run Flow Rate
- The C_v of the Equalising Valve

5.2 Meter Run Flow Rate

We know that temperature cannot be considered a “controlled variable” during such a test, so its “effect” was further considered.

Fortunately, the change in operating temperature was small (typically 3ºC) and therefore the primary effect of a change in temperature would be the associated change in the value of operating density.

As changes in operating pressure also follow this same rule, if it can be shown that a change in density within the flowing stream is compensated for by the effects of other factors within the general ISO 5167-1:1991(E) equation, then (for the effects of the meter run flow), variation in flow rate (principally differential pressure) can be considered as the “prime” site test parameter.

Section 6.0 of this report demonstrates that this is the case (but with a small effect due to expansibility which has been quantified accordingly).

5.3 Equalising Valve C_v

A typical equation to calculate the C_v (flow coefficient) of a needle valve is referenced below;

To determine the Cv or flow of a **gas** @ 70° F (21° C):

$$\mathbf{Cv} = \frac{\text{SCFH}}{1360\sqrt{\dfrac{(\Delta p)\,(p_1)}{(460+T)\,(S.G.)}}} \quad \text{or} \quad \mathbf{SCFH} = 1360\,Cv\sqrt{\frac{(\Delta p)\,(p_1)}{(460+T)\,(S.G.)}}$$

where: $\Delta p = p_1 - p_2$

p_1 = inlet pressure in psia

p_2 = outlet pressure in psia

SCFH = flow in standard cubic feet per hour

S.G. = specific gravity of gas where air = 1 @ 70° F (21° C) and 14.7 psia

T = temperature in ° F

Figure 5.5 – Typical C_v Equation

It can be seen that pressure is part of the equation and influences the "slope" of the response line as shown within the Figure 5.6 below.

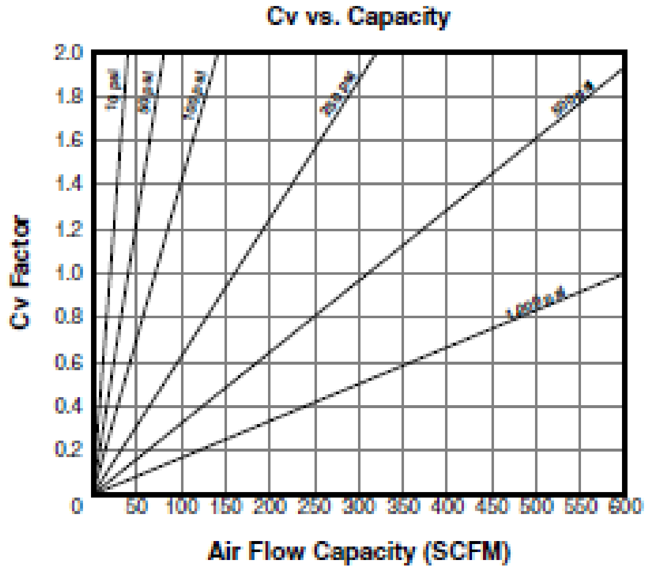


Figure 5.6 – C_v Factor Slope (Pressure Related)

The significance of changes in pressure across the equalising valve (and more importantly the effect on the differential pressure transmitter) cannot be ignored (as for the meter stream pressure changes – section 5.2 refers) and therefore site testing at different pressure(s) are required to quantify the effect(s).

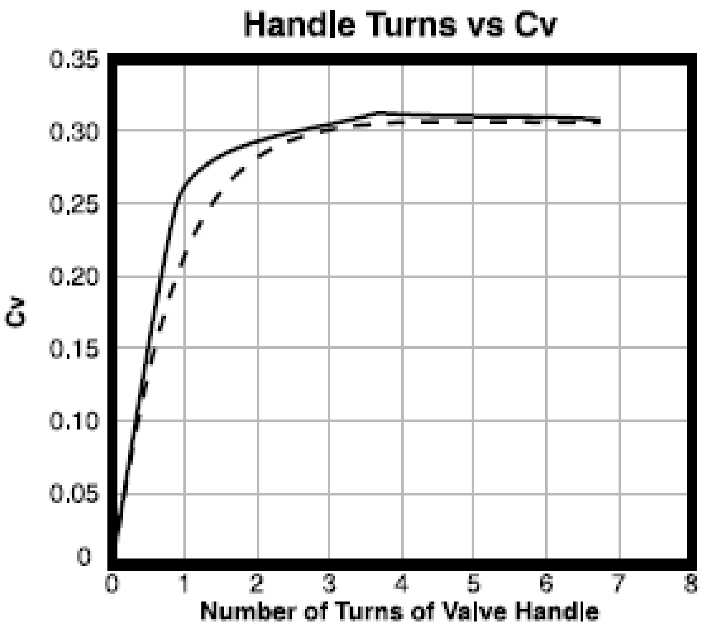


Figure 5.7 – Typical C_v versus Valve Position

Figure 5.7 shows the typical characteristic curve of valve C_v against the position of the valve (in reference to the number of turns open). This characteristic should be able to be replicated during the site testing and the subsequent results (section 7.0 refers).

5.4 Site Test Procedure

A site test procedure was developed as follows;

- Site testing to be performed at typically minimum, average and maximum flow rates seen during the SMER period were agreed;
  - 40 KSm^3/h
  - 70 KSm^3/h
  - 100 KSm^3/h
- Provision to graphically record in “real time” (preferably electronically) the outputs of the following measured variables to be made available;
  - Low ΔP
  - High (Duty) ΔP
  - High (Standby) ΔP
  - Pressure
  - Temperature
  - Density
  - Instantaneous Standard Volume Flow
- For each of the flow scenarios, the configuration of the flow metering stream was replicated (i.e. ΔP transmitter manifold equalising valve closed).
- Once a flow scenario had been replicated and established, the following actions were implemented;
  - Ensure all measured variables are recording satisfactorily and ensure a “date and time stamp” of some description is incorporated.
  - Open the ΔP transmitter manifold equalising valve (in steps of 1, 2, 3, 4, 5, 6 turns and finally fully open).
  - For each change in equalising valve position, ensure (allowing time for stabilisation) the recorded values have appropriately responded and identify on the recording device the “implemented equalising valve position change”.
- Repeat the above for all selected flow scenarios;

- Collate all records on completion of testing.

5.5 Site Testing – Completed Schedule

5.5.1 Site Test – 2nd August 2010

The site test procedure was implemented and completed. The results are referenced within section 7.0.

Due to operational constraints the site pressure could not be varied and all tests were completed within a pressure range of typically 1 Barg (54.45 to 53.36).

Whilst the results were "very similar" (within ±0.4%), it could not be definitively confirmed whether the small fall in operating pressure during the testing period contributed to the small change in error results or that it was more a function of the inherent uncertainty of the reproducibility of the test environment (i.e. for a practical site test this is as good as it gets!).

As it has been demonstrated within section 6.0 that changes in meter stream operating pressure produce an insignificant change in the flow error however, the potential changes to the manifold equalising valve characteristics cannot (at this stage) be ignored. For this reason, additional tests performed at a different pressure(s), were deemed a requirement.

5.5.2 <Further Site Testing to be included here in final report>

6.0 METER STREAM DENSITY EFFECTS

6.1 Introduction

As introduced earlier, due to operational limitations, the first site test was progressed at effectively one "limited" pressure range (54.44 – 53.36 BarG). Due to planned work schedules, it was unlikely that a significant step change in pressure (>10 Barg) could be accommodated in order to perform additional testing for some time.

Therefore, to eliminate the potential effects of other contributing factors bulleted below, a practical calculation reference method has been adopted.

- Pressure
- Temperature
- Gas Composition

The primary effect of a change in any of the parameters above would be their effect on density and it is this effect (or sensitivity) that is examined further.

6.2 Functional Relationship

Firstly, we know that the mass flow for the Braishfield "B" meter run is calculated according to the basic computation formula[1] for mass flow rate, given in the ISO 5167-1:1991(E) standard:

$$q_m := \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon_1 \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho_1}$$

Where:

q_m	Flow Rate	kg/s
C	Coefficient of Discharge	dimensionless
β	The Diameter Ratio	dimensionless
ε_1	Expansion Factor	dimensionless
d	Diameter of Orifice	m
Δp	Differential Pressure	Pa
ρ_1	Upstream Density	kg/m^3

It can be seen that if all the terms prior to the square root element could be considered a constant (K), then it can be confirmed that for a steady flow rate (q_m), any changes in density (ρ_1) would result in a proportional change in differential

[1] ISO 5167-1 1991(E) section 5.1, Equation 1

pressure (ΔP) and therefore only changes in ΔP need to be considered as a variable for site testing.

As a majority of the terms are either numerics or defined measurements (β, π and d), only C and ε_1 are dependant variables.

The Discharge Coefficient (C) is a function of Reynolds Number (Re) and Re is a function of Fluid Velocity and Kinematic Viscosity.

Expansibility (ε_1) is a function of the Pressure Ratio (P_2/P_1) and the Isentropic Exponent.

The effects of C and ε_1 are considered below.

6.3 Density Sensitivity Results

Using the OMNI flow computer data (configured during the initial site testing), KELTON® FLOCALC® was used to calculate the effects of changes in density.

Three values of density (representing the pressure ranges observed during the SMER duration) were configured within FLOCALC® for each of the 3 test flow rates and the differential pressure adjusted to keep the flow rate constant. For each density value, the corresponding values for C and ε_1 where recorded.

The results are tabulated over page.

It can be seen that due to the high operating Re (typically 9×10^6 to 11×10^6), no change to C was noted. Therefore C can be considered constant.

However, small changes in ε_1 where noted. The maximum effect (in the high differential pressure case #1) equates to 0.1% over a 20 BarG operating range (average of 0.0053% per BarG).

As the initial flow test results for the high and medium differential pressures exhibited a difference in average error of 0.4% (across the linear error between 4 turns and fully open), the maximum 0.1% pressure effect value (in the overall SMER) can be considered negligible.

It is therefore concluded that only changes in ΔP need to be considered (with regard to meter stream operation) during the site testing requirement to provide a representative replicated error result.

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6.0 METER STREAM DENSITY EFFECTS

TEST#1 - Changes in Discharge Coefficient and Expansibility due to Density Effects (High-Flow Rate)						
Pressure BarG	Density Kg/m^3	Differential Pressure (mbar)	Pressure Ratio P^2/P^1	Flow Rate (Ksm^3/h)	Discharge Coefficient	Expansibility
50	42.955	294	0.0059	150.0	0.603886	0.997921
60	52.646	234	0.004	150.0	0.603886	0.998584
70	62.756	201	0.0028	150.0	0.603886	0.998980
				Difference (%)	0.00	Average 0.0053%/BarG

TEST#2 - Changes in Discharge Coefficient and Expansibility due to Density Effects (Mid-Flow Rate)						
Pressure BarG	Density Kg/m^3	Differential Pressure (mbar)	Pressure Ratio P^2/P^1	Flow Rate (Ksm^3/h)	Discharge Coefficient	Expansibility
50	42.955	200	0.004	123.7	0.603911	0.998587
60	52.646	163	0.0027	123.7	0.603911	0.999037
70	62.756	137	0.0019	123.7	0.603911	0.999307
				Difference (%)	0.00	Average 0.0036%/BarG

TEST#3 - Changes in Discharge Coefficient and Expansibility due to Density Effects (Low-Flow Rate)						
Pressure BarG	Density Kg/m^3	Differential Pressure (mbar)	Pressure Ratio P^2/P^1	Flow Rate (Ksm^3/h)	Discharge Coefficient	Expansibility
50	42.955	65	0.0013	70.6	0.604006	0.999541
60	52.646	52.6	0.00088	70.6	0.604006	0.999687
70	62.756	62.7	0.00064	70.6	0.604006	0.999774
				Difference (%)	0.00	Average 0.0012%/BarG

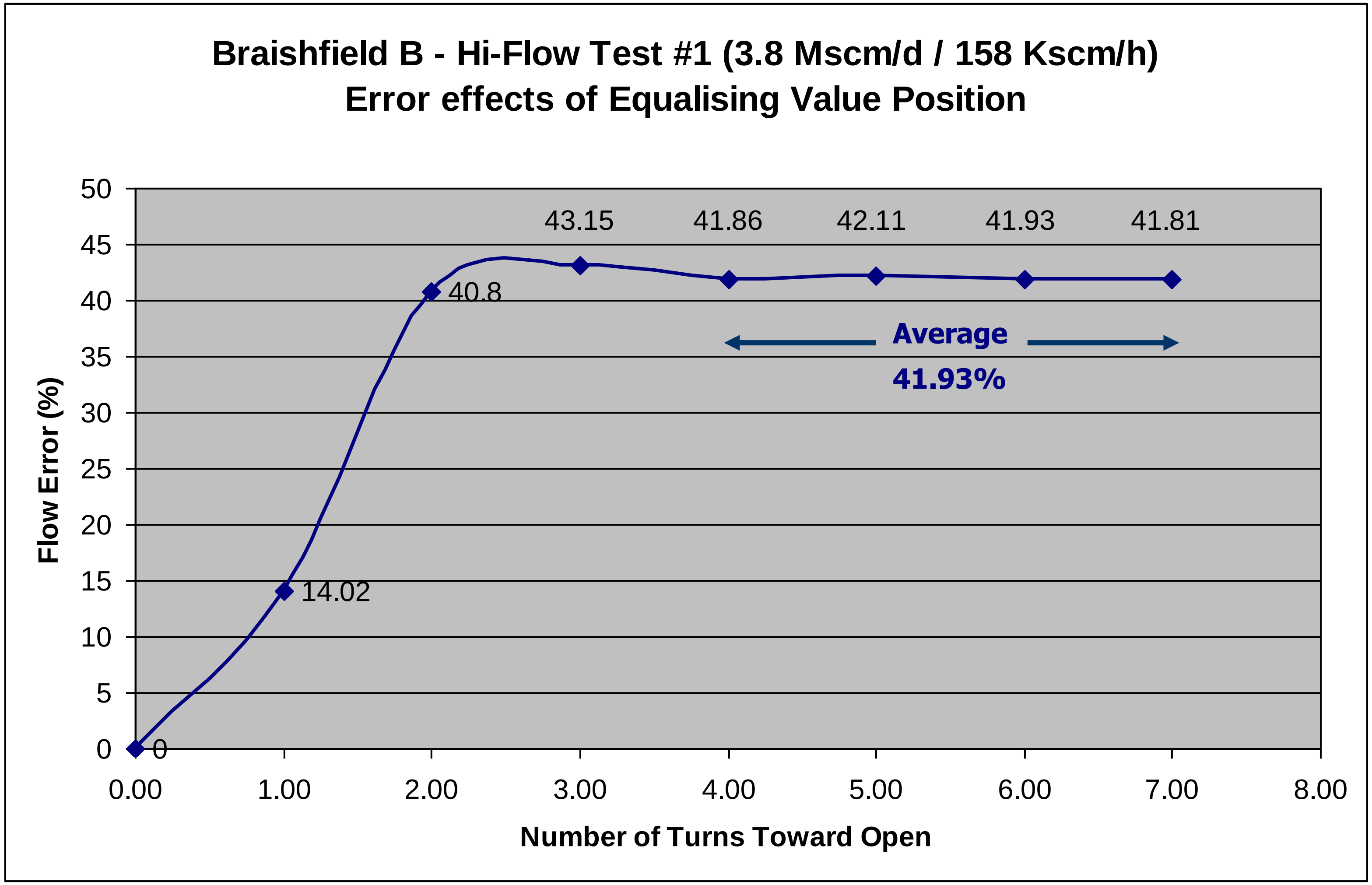

Figure 7.1 – High Flow Test Results

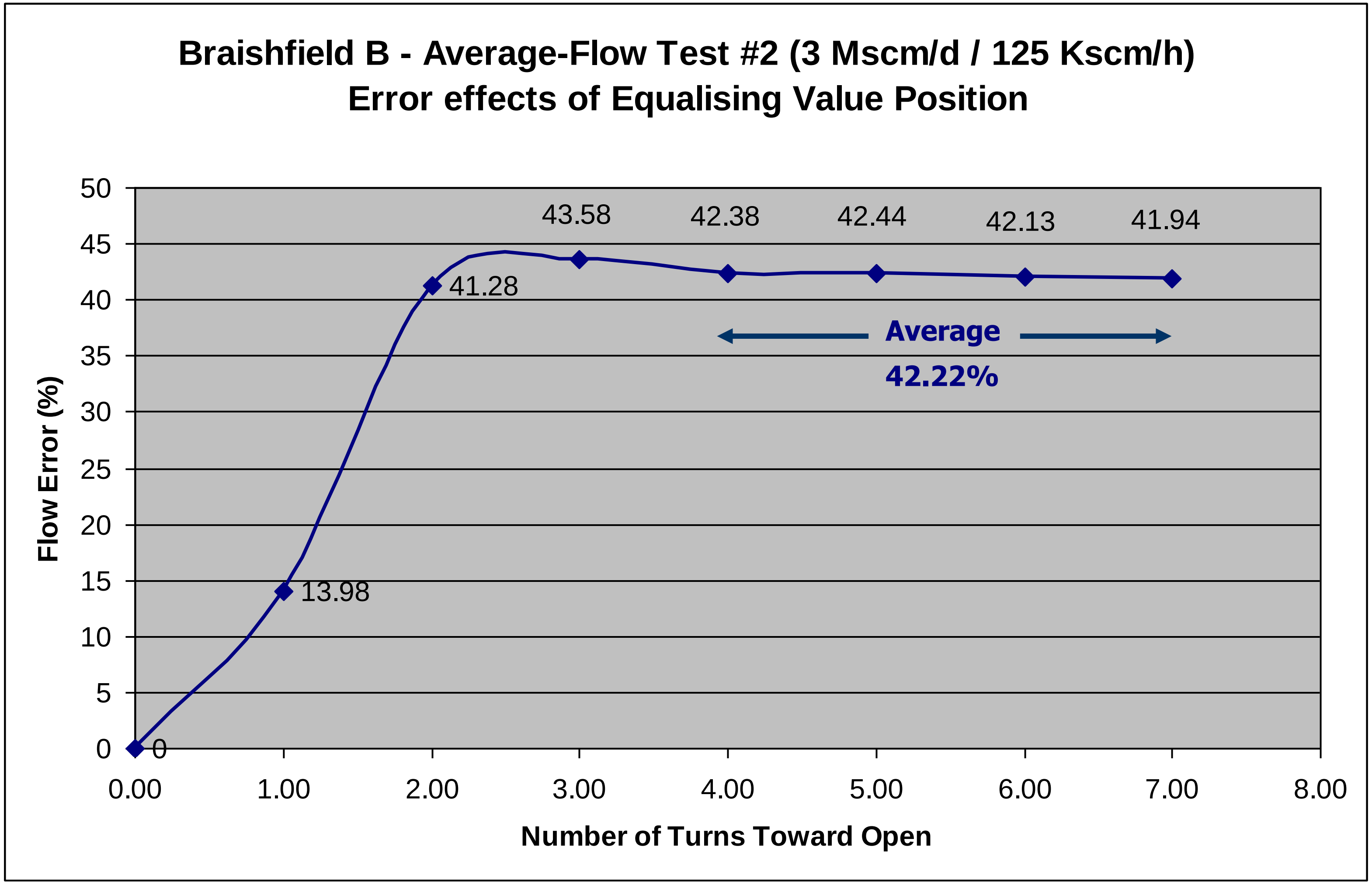

Figure 7.2 – Average Flow Test Results

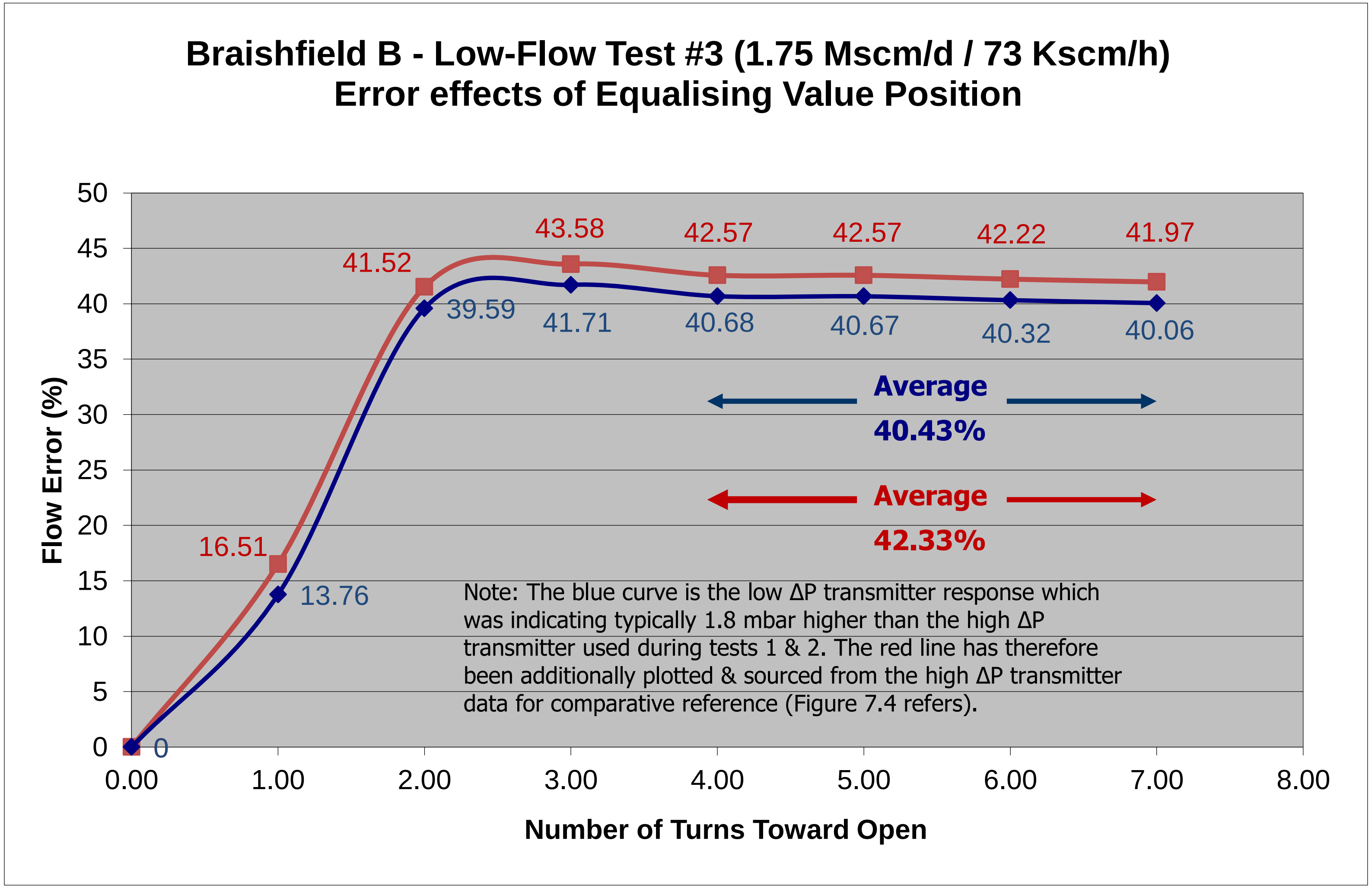

Figure 7.3 – Low Flow Test Results

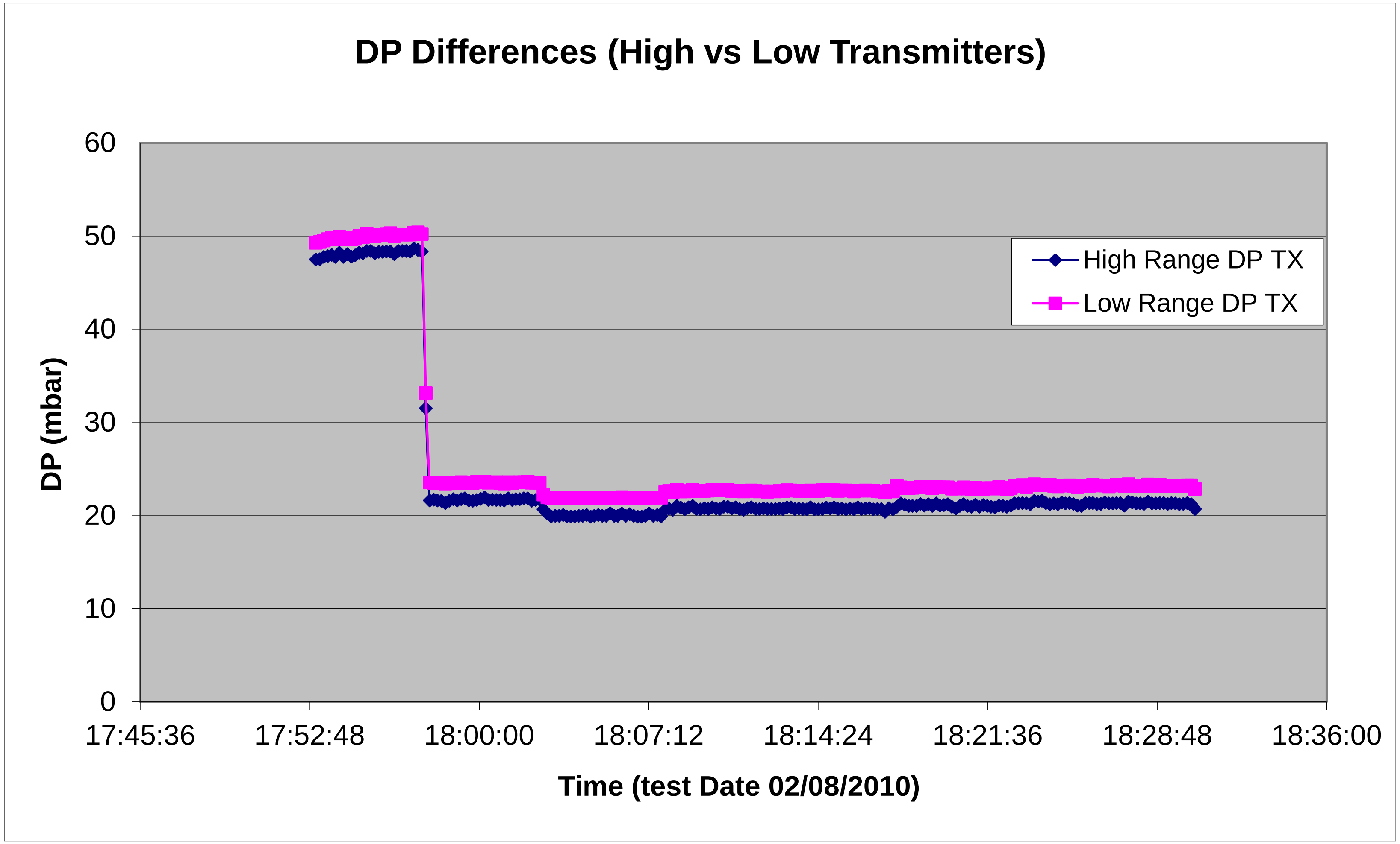

Figure 7.4 – High vs Low Differential Pressure Transmitter Readings (Typically 1.8 mbar)

8.0 CONCLUSIONS

The results of the initial flow tests (performed on 2nd August 2010) produced results that were "very similar" but it could not be definitively confirmed whether the small fall in operating pressure during the testing period contributed to the small change in error results or that it was more a function of the inherent uncertainty of the test environment.

Whilst section 6.0 of this report demonstrates that pressure differences would produce only a second order effect, it is unclear at this point of the SMER review if pressure differences will have an effect on the manifold equalising valve characteristics.

For this reason, additional tests are required to be performed at a significantly different pressure (typically 10 Barg) to ensure that any "shift" in the error results (section 7 refers) can be clearly attributed to a change in equalising valve characteristics or that indeed that the "spread" of error results are a function of the reproducibility of the test environment uncertainty.

It is understood that a higher pressure test will be performed during late October 2010.

9.0 RECOMMENDATIONS

Until all system testing has been completed, it would not be appropriate to provide any detailed recommendations at this time.