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Aberdeen SMER SC006

20th August 2013

Overview

- Background
- Error Description
  - Analysis of flow data
- Initial Tests
- Carrier Checks
- Carrier Data Plates
- Orifice Plate Photographs
- On-site Testing
- CFD Analysis
- Results
- Summary of Error Periods

Background

- Orifice plate meters are used to accurately measure mass flow rate
  - The orifice plate creates a pressure drop (Δp) related to flow rate (q_m)

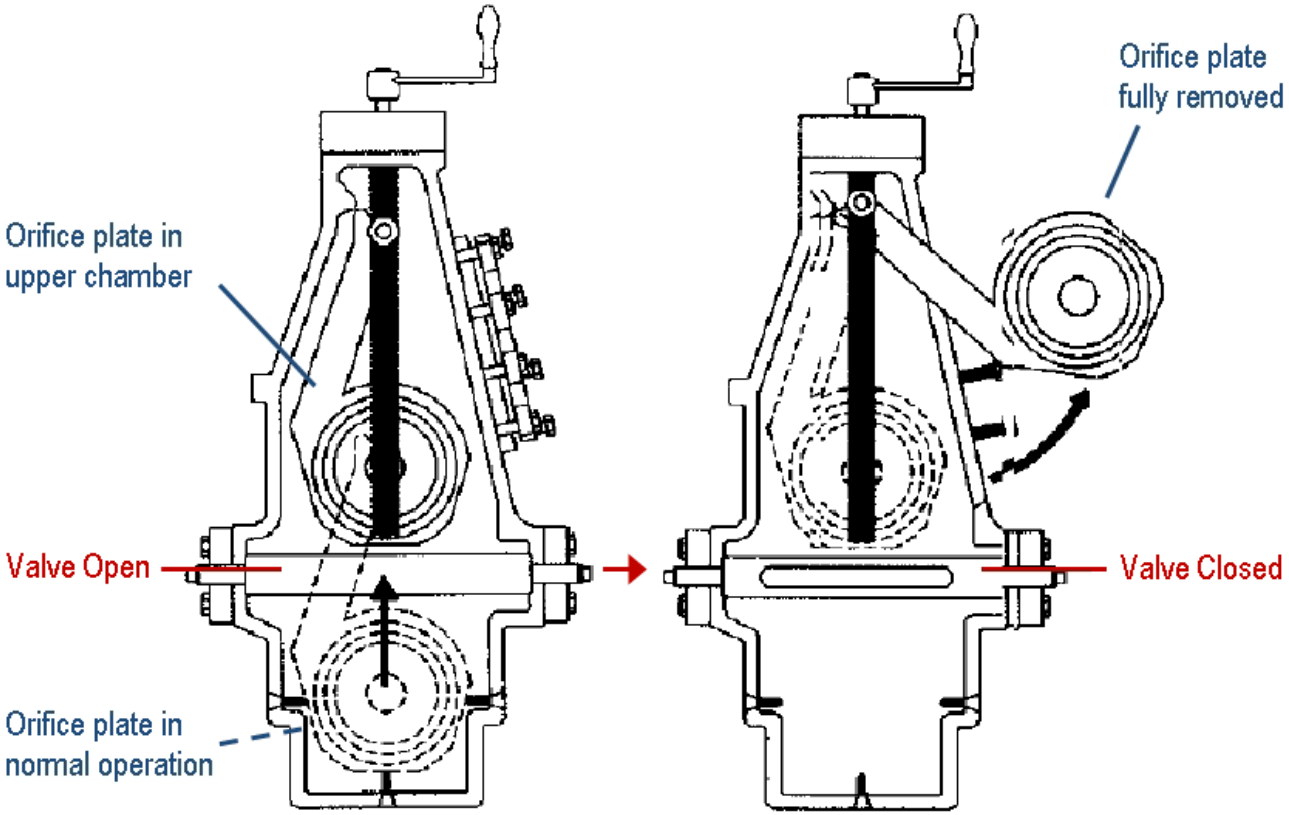
$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_1}$$

- This calculation is carried out within a dedicated flow computer algorithm
  - In accordance with ISO 5167-1:1991
- It assumes that the plate is located concentrically within the pipe
- If the plate is located eccentrically then the equation is not valid
  - Tolerance in this case is 0.5 mm
  - (or up to 1.0 mm with 0.3% additional uncertainty)
  - Some further guidance exists up to 12.8 mm eccentricity

Background

- The orifice plate is typically placed inside a carrier mechanism
  - To enable accurate location of the orifice plate within the pipe
- This carrier is designed to allow maintenance on the orifice plate without venting the metering pipe work
  - Two chambers separated by a valve
- This carrier is unusual in design because the valve is open during service

Background


Orifice plate
fully removed
Orifice plate in
upper chamber
Valve Open
Valve Closed
Orifice plate in
normal operation

Error Description

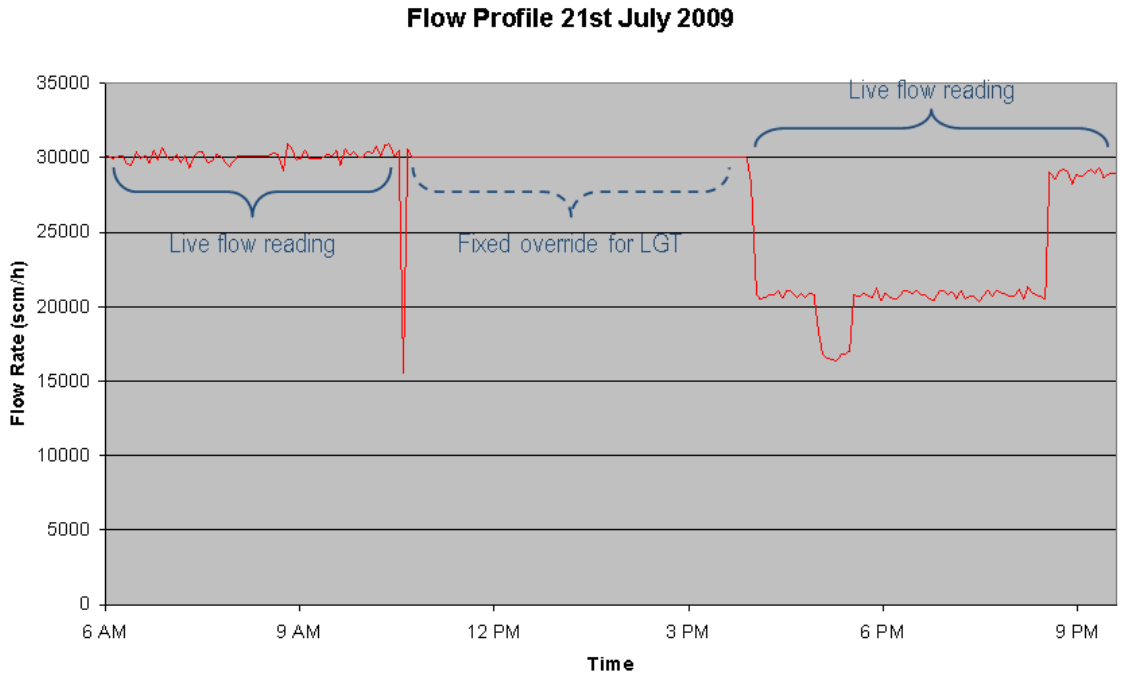
- 7th August 2010 - Fault logged
  - 'Possible metering issues' following line pack calculations
- 10th August 2010 - Advised that the orifice plate was not set correctly
  - DP of 54 mbar was showing as 6 mbar
  - Flow of 1.42 Mscm/d was shown as 0.5 Mscm/d
- Subsequent interviews with mechanical operatives provided some confidence that the counter was set at 99950 following the orifice plate change on 27th July 2010
- Unable to confirm counter reading at start of orifice plate change on 27th July 2010
- Unable to confirm counter reading at orifice plate change on 21st July 2009

Error Description

- Site controlled to flow rate set point and pressure overrides
- During normal orifice plate changes the flow control valve is set to direct valve control to prevent movement of the valve due to spurious signals
- On 21st July 2009 and 10th August 2010 a step change in flow rate can be seen
- On 27th July 2010 the flow rate was transient
  - Flow rate was not maintained because of minimal pressure differential across the site
- On 5th August 2008 there was no change in flow rate

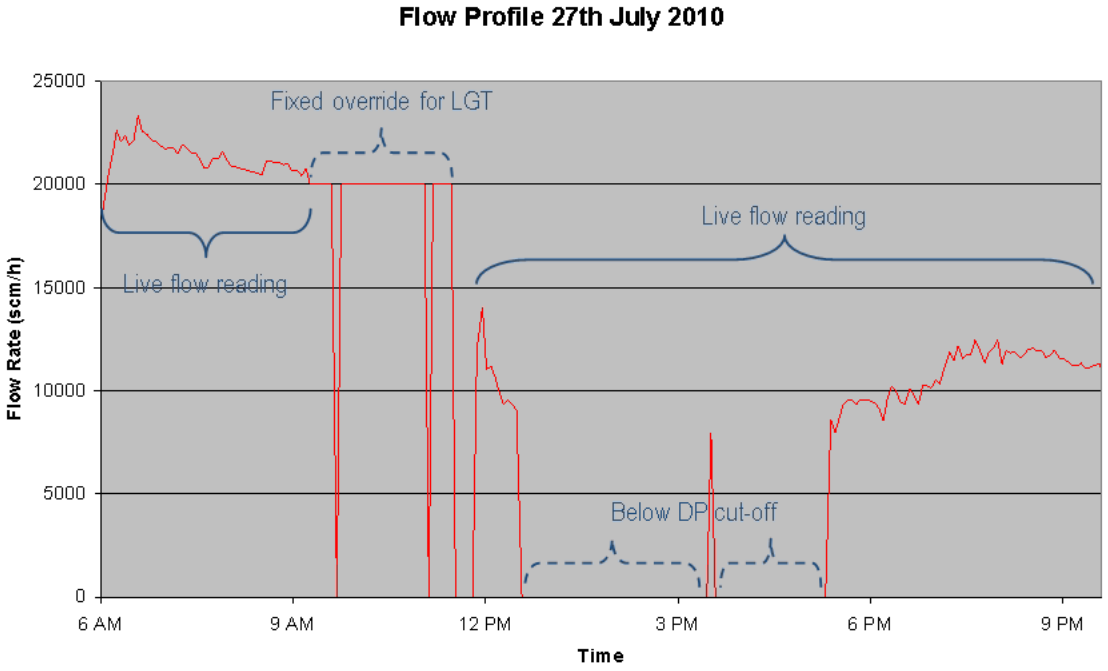
Error Description

- 21st July 2009 – Problem was introduced at orifice plate change
  - ~30 kscm/h site flow prior to plate change
  - ~21 kscm/h site flow following plate change
  - Indicates an under-registration of 31 % following change



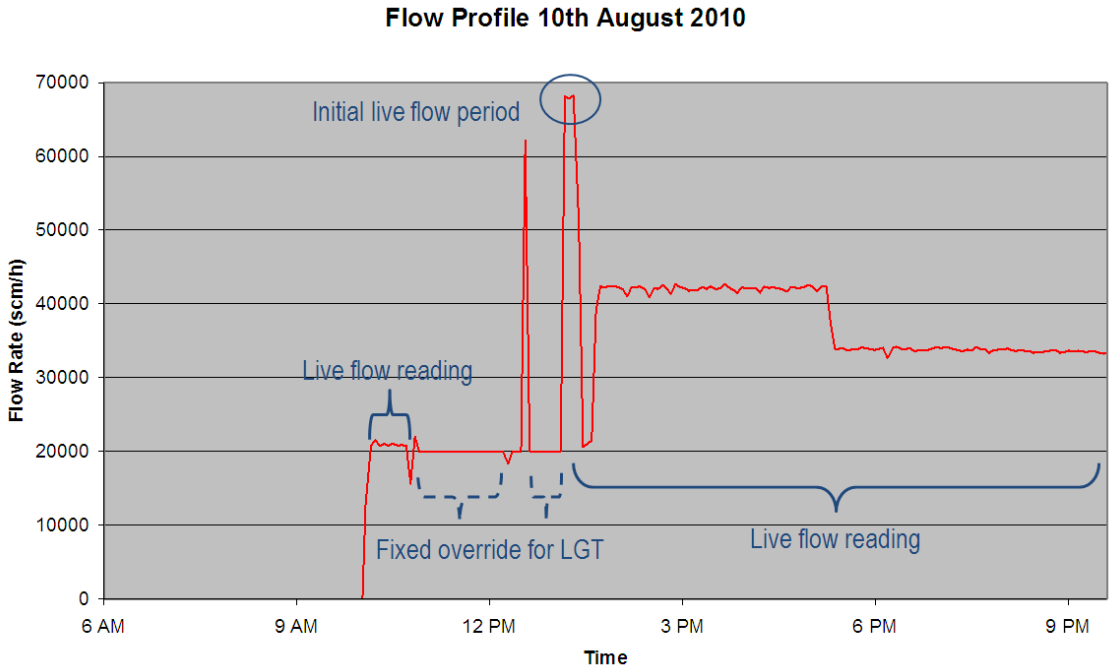
Error Description

- 27th July 2010 – Orifice plate was changed
  - Transient flow rate before and after plate change
  - No direct comparison available
  - DP was close to the low cut-off and some zero flow rates were recorded



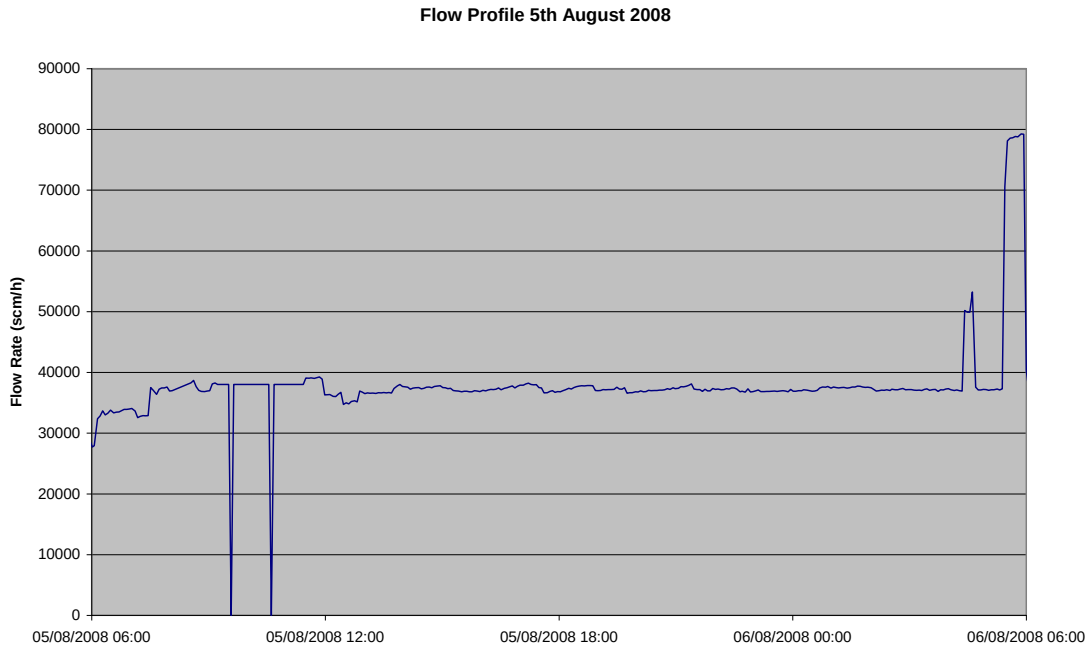
Error Description

- 10th August 2010 – Fault corrected
  - ~21 kscm/h site flow prior to correction
  - ~68 kscm/h site flow following correction
  - Indicates an under-registration of 69 % before correction



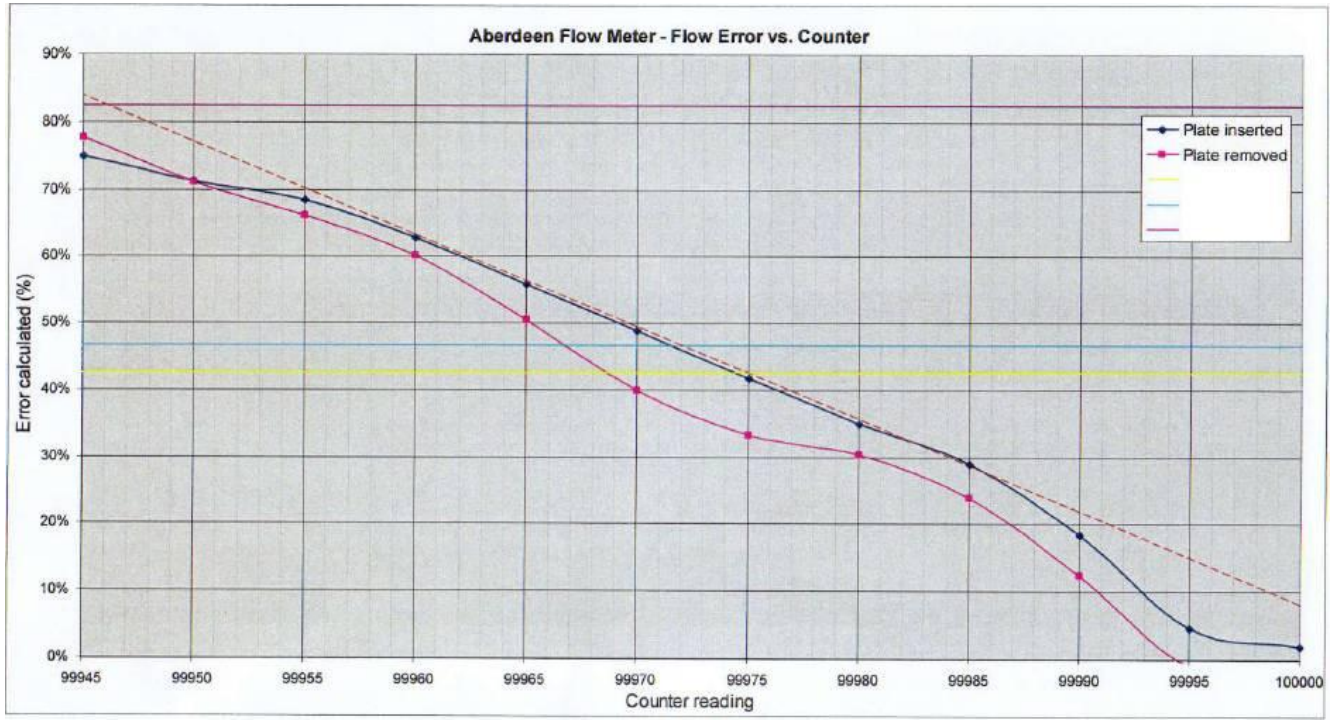
Error Description

- 5th August 2008 – Correct orifice plate change
  - ~38 kscm/h site flow prior to plate change
  - Fixed flow (38 kscm/h) recorded for duration of plate change
  - ~38 kscm/h site flow following plate change



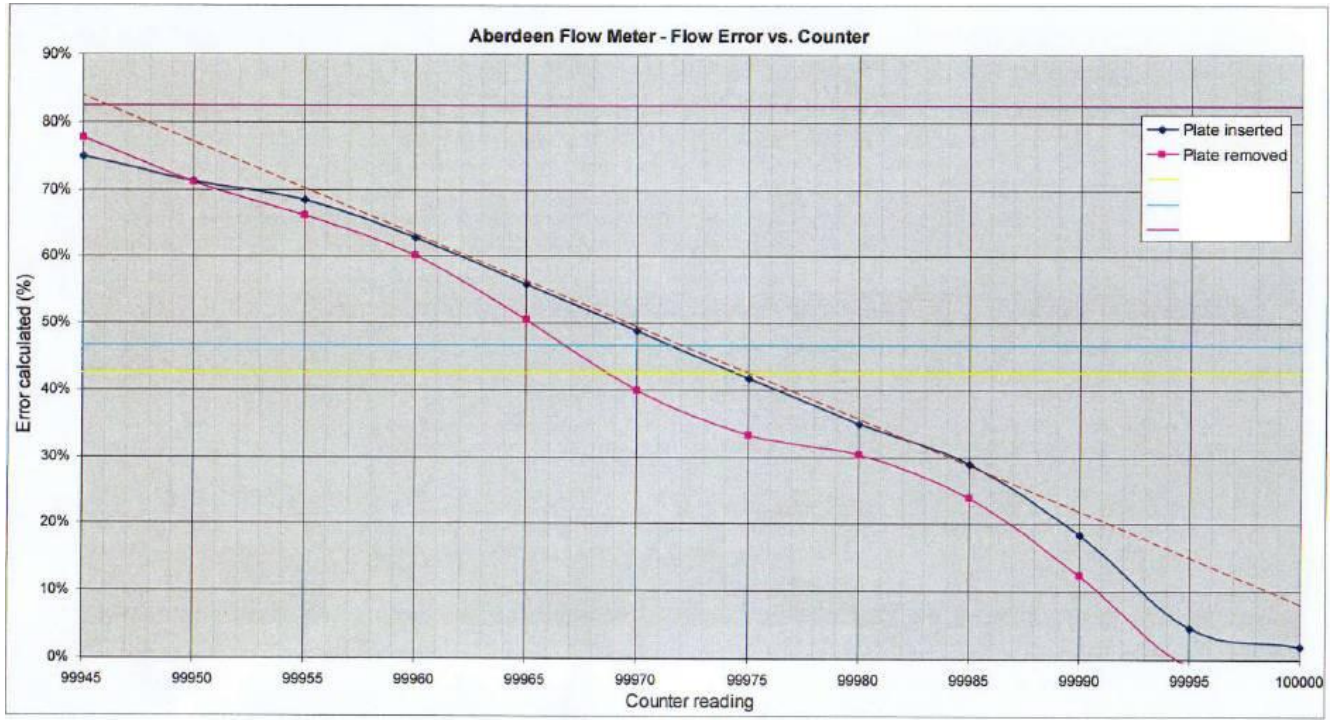
Initial Tests

- Initial tests were carried out by downstream party to estimate error magnitude
  - Prior to appointment of ITE
  - Not suitable as quantification of error



Initial Tests

- Error at 99950 counter reading shown as 71%
  - Compares well with 69% estimated from step change
- Step change of 31% suggests that the unknown counter reading is ~99984

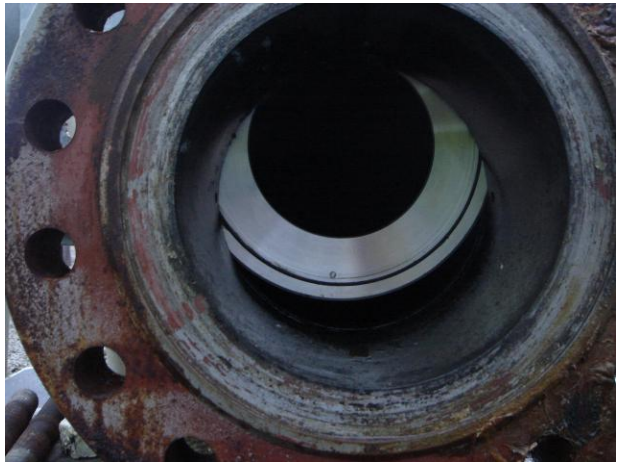


Carrier Checks

- Aimed to determine the relationship between the counter reading and the physical location of the plate within the pipe
- Downstream spool removed
- Vertical and horizontal offsets measured
  - Using slip gauges
  - At various counter readings on removal and insertion

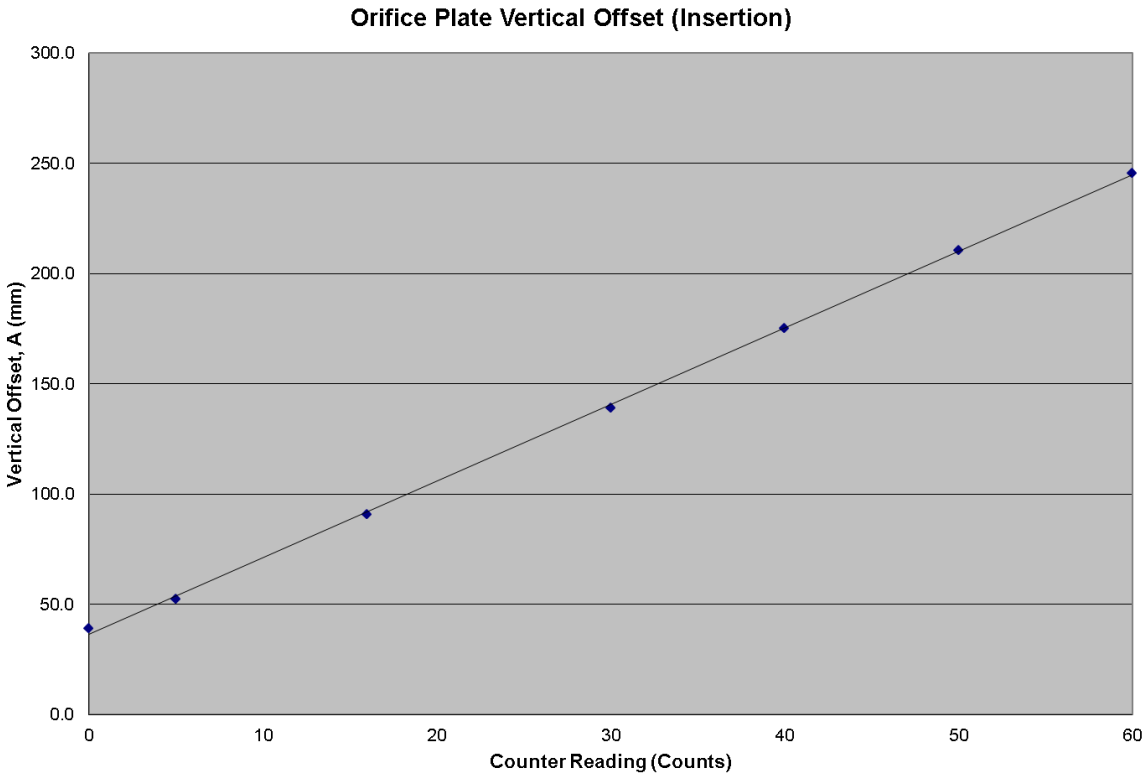
Carrier Checks

- 00000 Correct location (top right)
- 99950 Correct location (bottom right)
  - Offset of 173.0 mm
- 99984 Correct location (bottom left)
  - Offset of 51.3 mm



Carrier Checks

- Linear profile



Carrier Checks

- Average of three readings
- 99950 - No difference in readings
- 99984 - Standard deviation less than half of the measurement uncertainty
- Good repeatability

Carrier Data Plates

- Identification plate
  - Serial number and carrier specification
- Information plate
  - Step by step Instructions on removal and insertion of orifice plate
  - Not easily readable

Carrier Data Plates

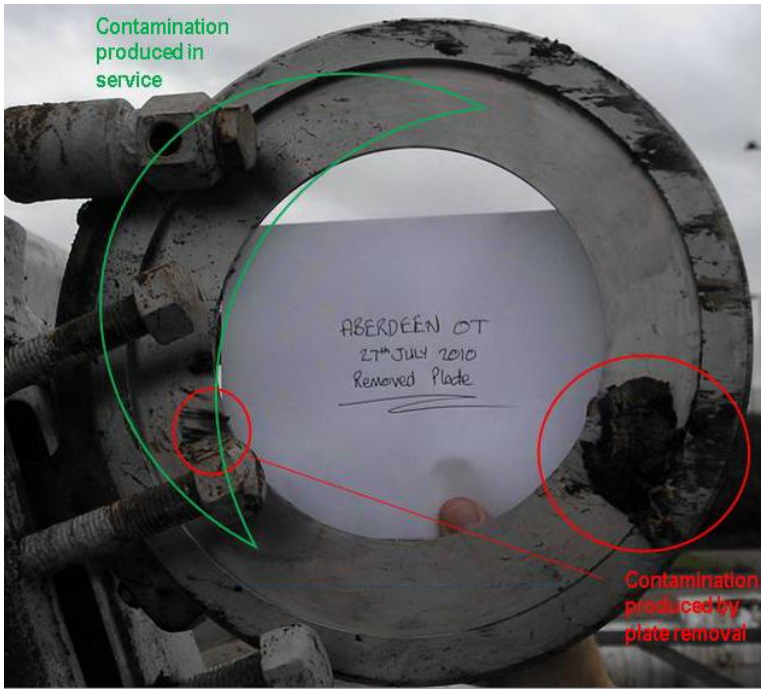
- The information plate states that the fully inserted position should be at a counter reading of between 9995 and 0005
  - Five digit counter
  - Fully inserted position is exactly 00000
- From this it can be seen that the four digit 9995 counter reading was likely to have been misinterpreted as a five digit reading of 99950
- No evidence to support a counter reading of 99984 (estimated from initial analysis)
- However it was thought that the 99**8**85 which is stamped in two locations on the carrier information plate could have been misread as 99**9**85

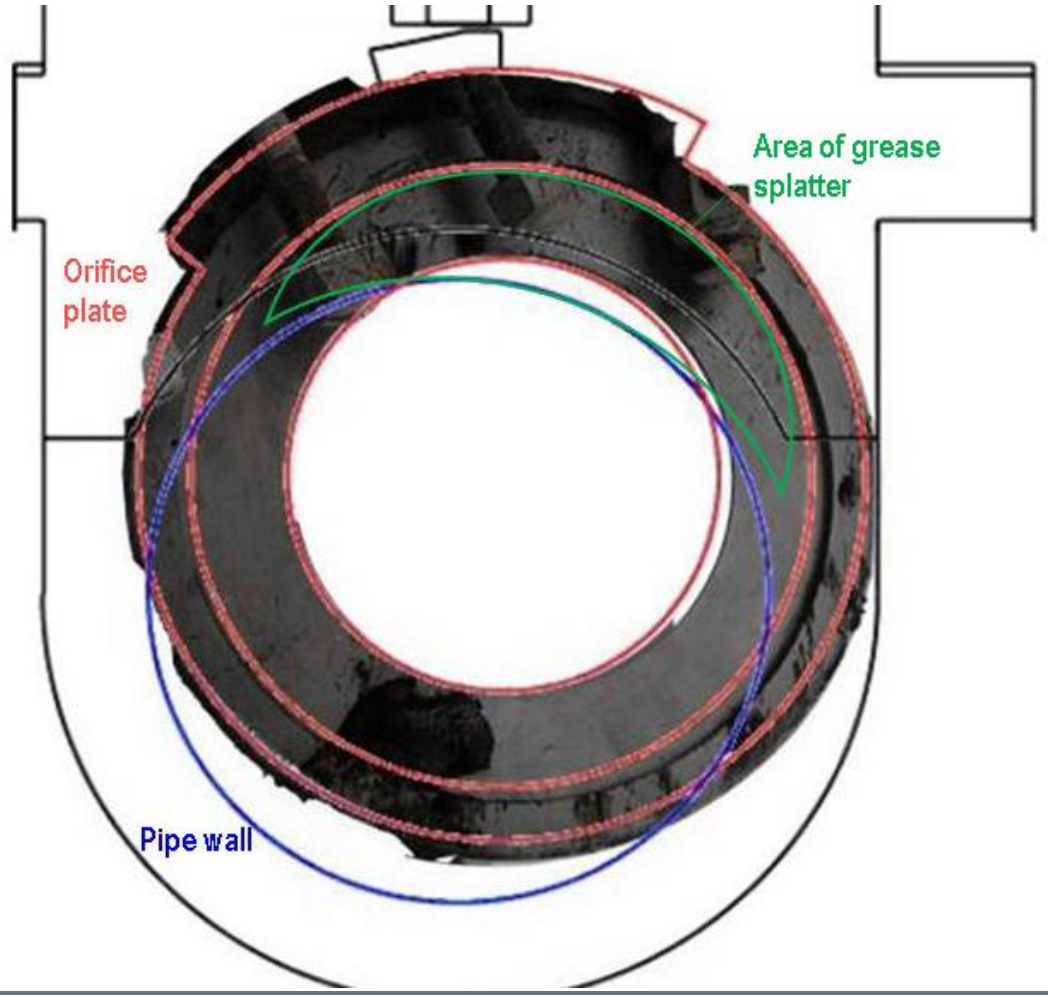
Orifice Plate Photographs

- Photographic records are kept of each plate (both faces) on insertion and removal
- Plate removed on 21st July 2009 was clean
- Plate removed on 27th July 2010 showed some contamination
  - Location supports 99985 counter reading
- Plate removed on 29th July 2011 showed some contamination
  - Pattern consistent with normal flow conditions
  - No significant effect based on quantity and location

Orifice Plate Photographs

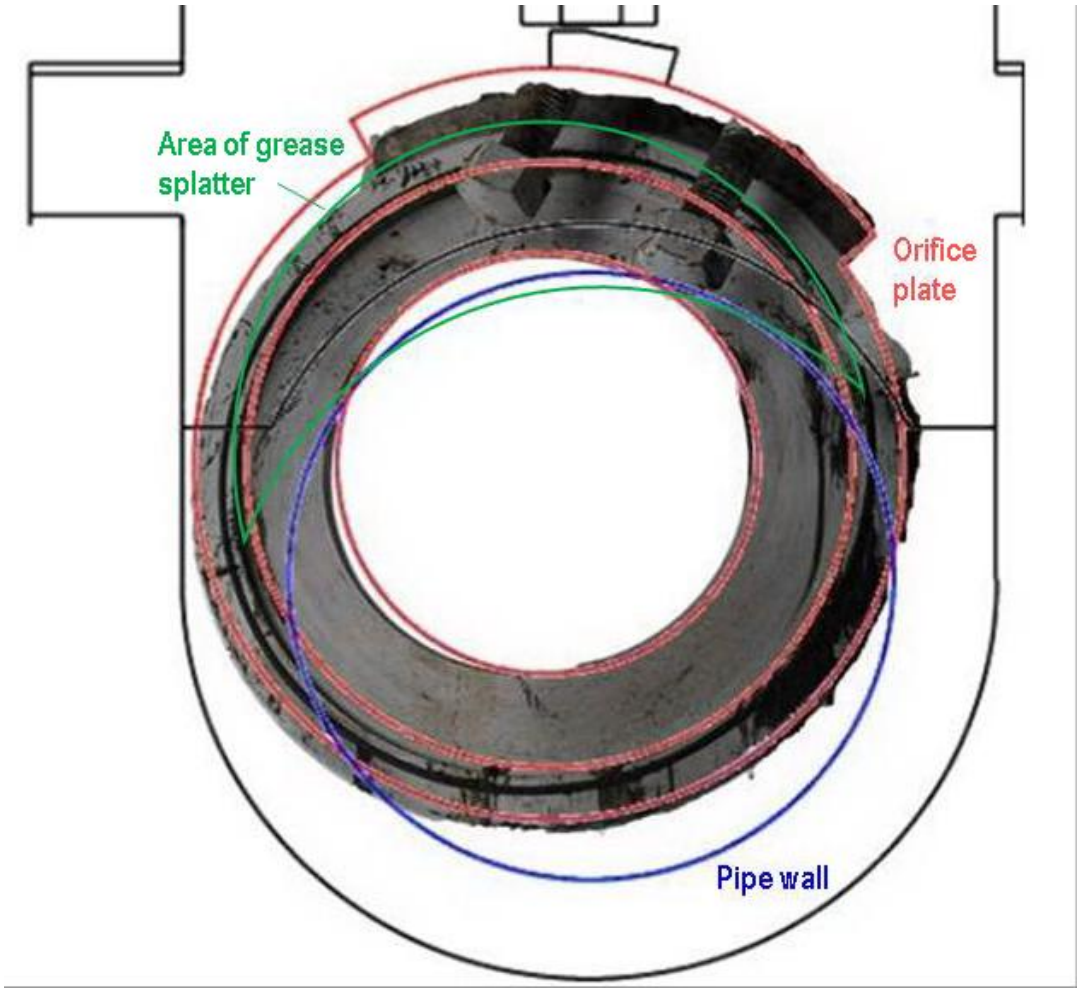
- July 2010, Upstream





Orifice Plate Photographs

- July 2010, Downstream

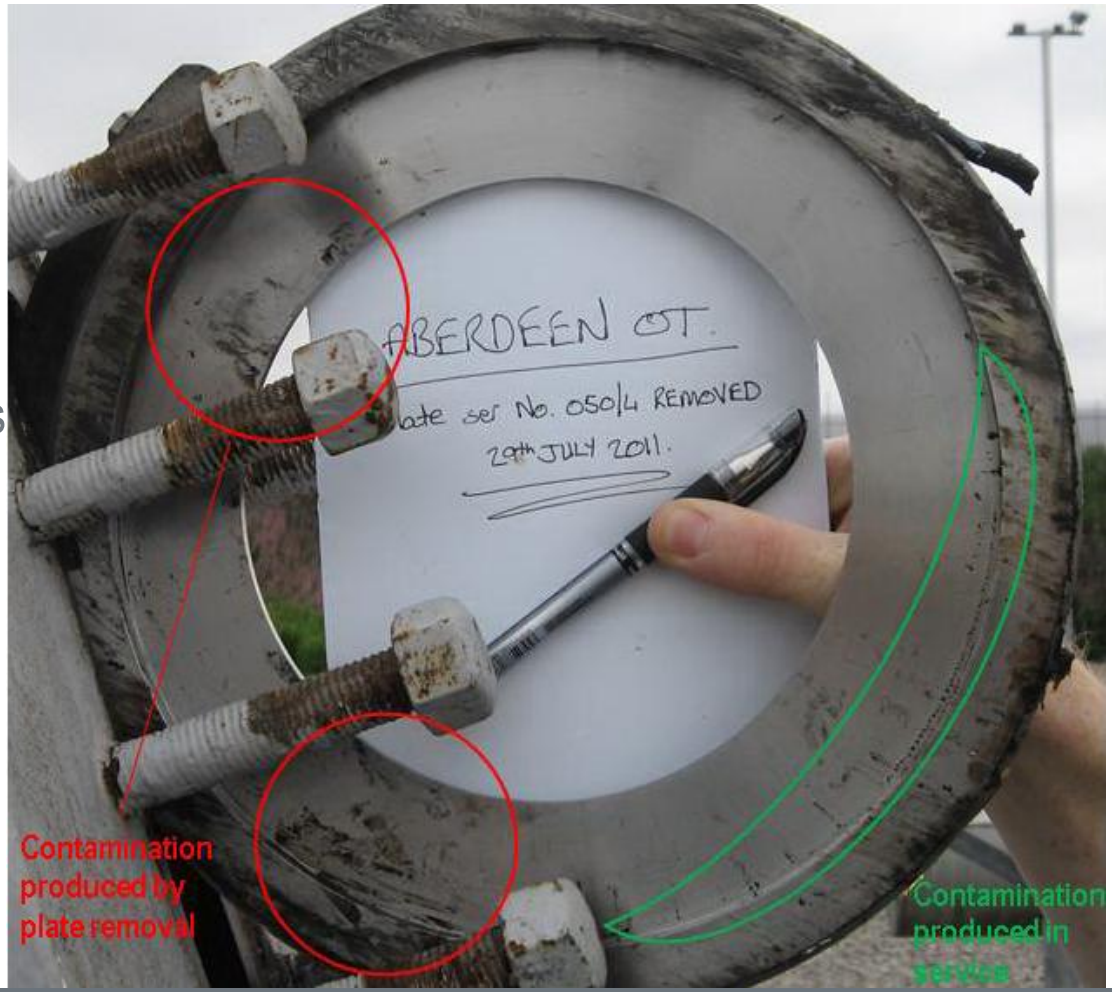


Orifice Plate Photographs

- The splatter pattern suggests small amounts of grease being picked up and deposited by a flow of gas
- Contamination of this kind would be removed by the flow of gas under normal operating conditions (higher flow rates), particularly around the bore edge
- This is an indication that normal gas flows were not experienced by this part of the orifice plate

Orifice Plate Photographs

- July 2011, Upstream
- Typical of minor contamination experienced in service
- Confined to outer annulus
- Streaking radially outwards



On-site Testing

- Aim to establish the relationship between DP and the counter reading at various flow rates and pressures
- Designed to cover the true range experienced during the error period
- Pressure - 54.8 barg to 66.5 barg
- Site maximum flow - 4.5 Mscm/d
- Minimum flow rate - 1.0 Mscm/d
  - Selected because of high uncertainties at lower flow rates

On-site Testing

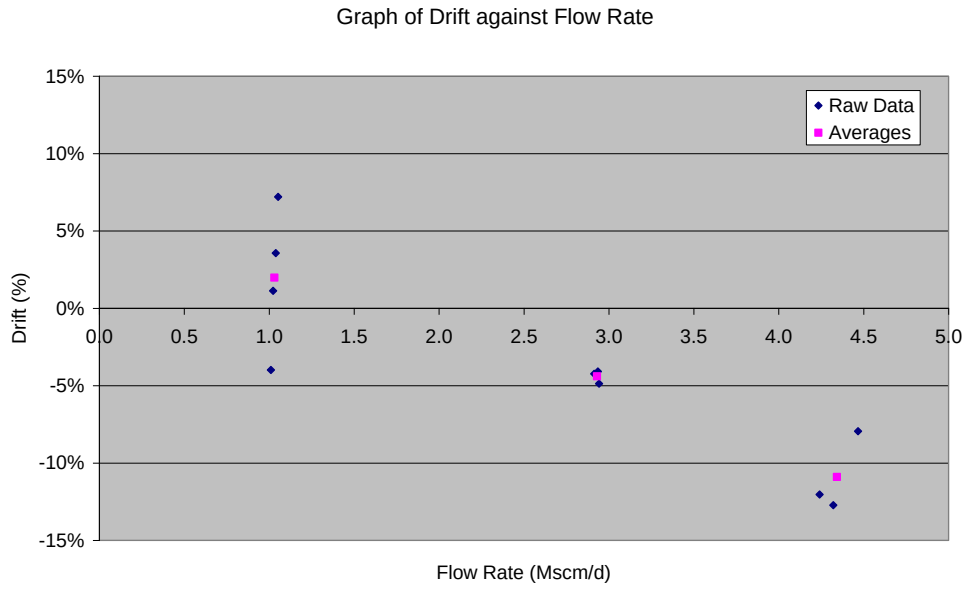
- Problems achieving desired pressures in upstream National Transmission System
- 15th February 2012 the pressure was between 61.4 barg and 62.1 barg
  - Selected as intermediate pressure point
- Aimed to test at 66 barg and 55 barg
  - It was suggested that 57 barg was a more achievable target
- 18th April 2012 the pressure was between 63.6 barg and 64.0 barg
  - Selected as high pressure point
- 19th April 2012 the pressure was between 58.1 barg and 58.7 barg
  - Selected as low pressure point
- Pressure range was deemed to be acceptable as it covered >85% of the data
  - Later shown to be insensitive to pressure

On-site Testing

- Pressure maintained by upstream party
- Set flow control valve in direct valve control to fix flow rate
- Positioned plate at various counter readings (removal and insertion)
- Logged process data (DP, erroneous flow rate, etc)
- Repeated for 3 different flow rates at 3 different pressures
- Some instability in flow rate and pressure (pre- and post-check)

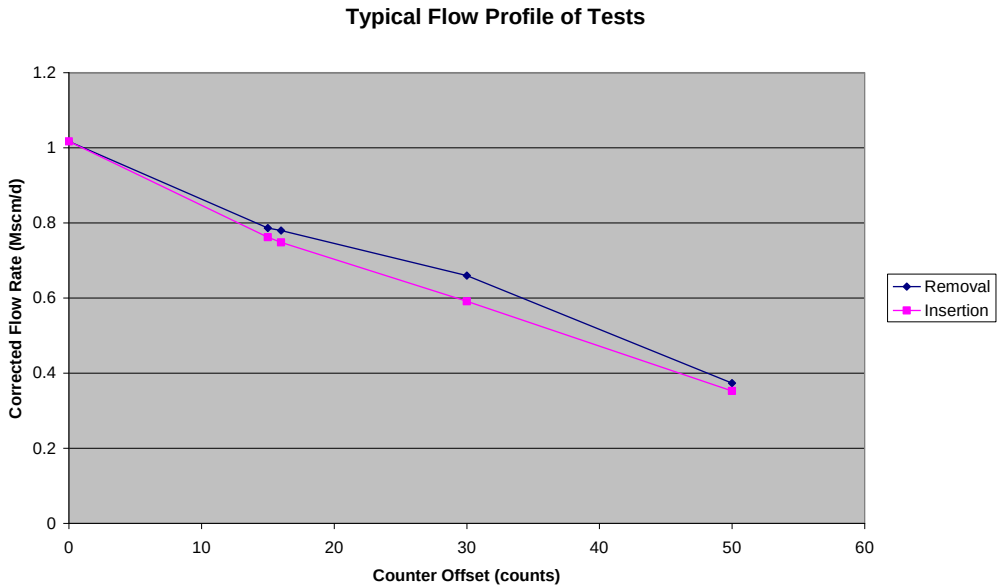
On-site Testing

- Flow rate drift was caused by mis-match between the supplied flow rate and the downstream demand (~2 Mscm/d)
- This was most prevalent at the highest flow rates (i.e. where the difference between supply and demand was at it's the greatest)
- Assumed to be linear over the duration of each test



On-site Testing

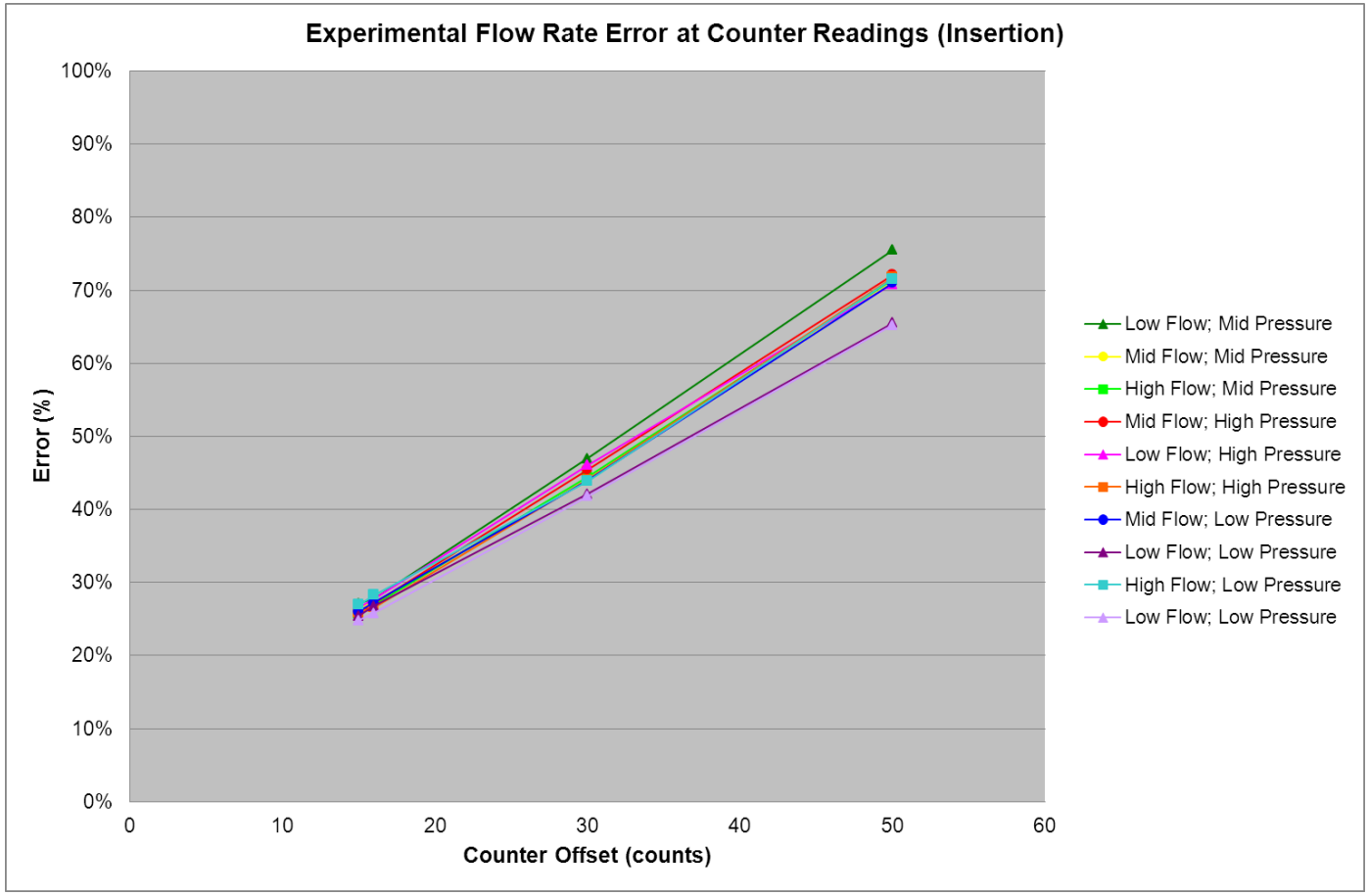
- At each point there was a slight difference in results between removal and insertion due to the difference in direction of the horizontal offset
  - Plate moves towards the differential pressure tapping points on removal and away from them on insertion
- Results in slightly higher flow rates on removal



On-site Testing

- Assumed that orifice plate was inserted to the counter reading, rather than inserted fully and then removed back out to the counter reading.
- It cannot be known for sure, but is more plausible and much more likely

Results - Experimental



CFD Analysis

- No guidance or research for such severe misalignment
- Validation of model
  - Validated against correctly located operating and experimental data
  - Validated against 99970 incorrectly located data
- Results produced for 99985 and 99950 counter readings
  - Experimental DP results not supplied until CFD results were completed
- Recommendations of peer review of analysis report
  - Shorter model (shown to be less accurate)
  - Grid independence checks (completed)
  - 0.1 mm resolution around orifice edge (resolution increased but recommendation not met)
  - Additional reporting requirements (completed)

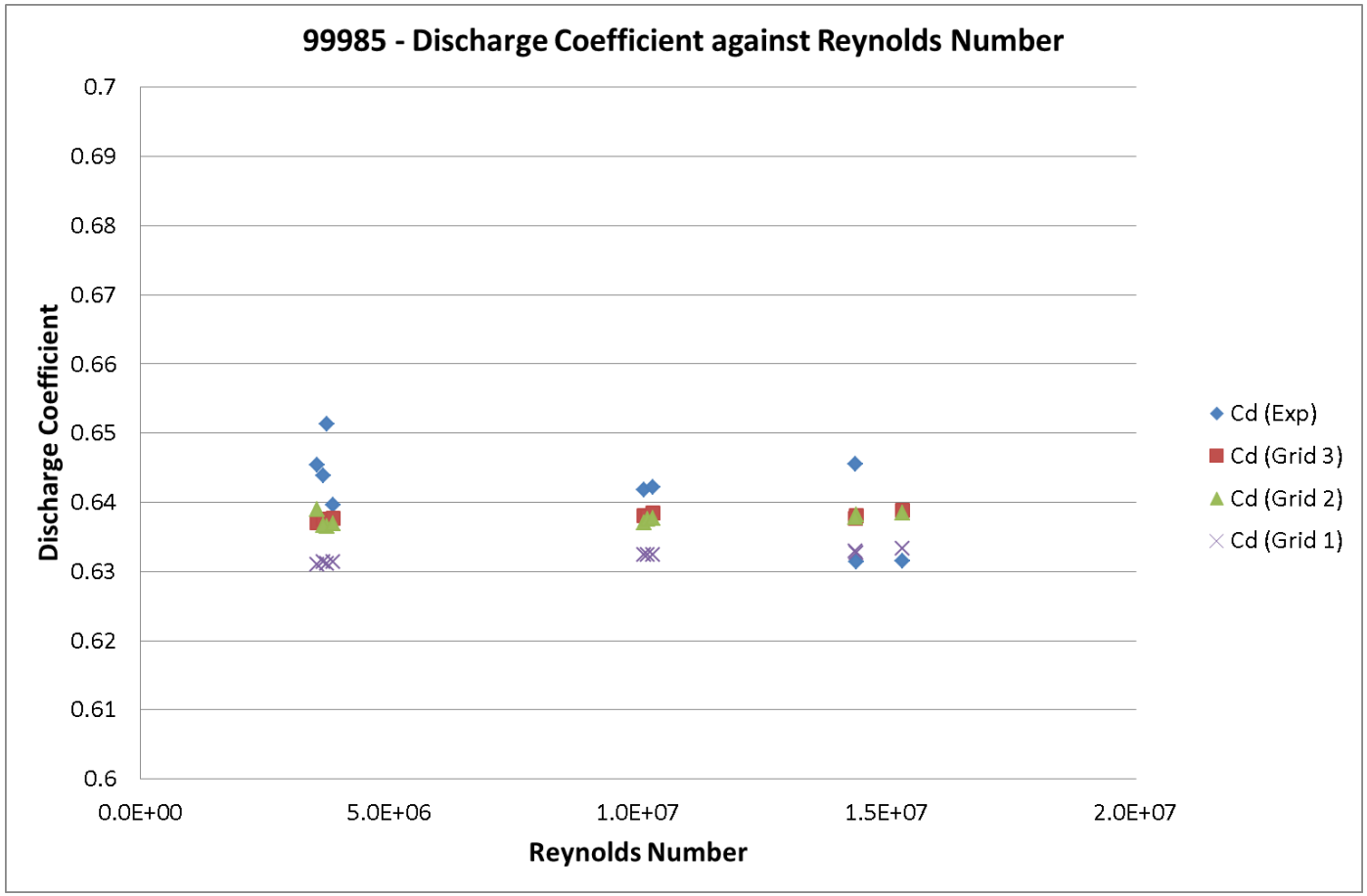
CFD Analysis

- Comparison of CFD and experimental results
  - DP measurement uncertainty used as acceptable tolerance
  - Grid independence considered acceptable under 1%
- 99985 counter reading
  - 7/10 within DP measurement uncertainty
  - Other three were up to 2.5% (vs. 1%)
  - All grid independent (< 0.5%)
- 99950 counter reading
  - 6/10 within DP measurement uncertainty
  - Two others on limit of tolerance (42% vs. 40% and 2.6% vs. 2.5%)
  - Other two were 10% and 4.2% (vs. 6% and 2.5%)
  - All grid independent (< 0.7%)
- All results show error to be independent of process conditions

Results - CFD - 99985

Test	Actual Flow Rate (m^3/h)	Experimental DP (mbar)	CFD DP (mbar)	Error (%)	DP Measurement Uncertainty (%)
1	594.4561	13.78	14.40	-4.5 %	5.0 %
2	1598.6628	103.14	104.36	-1.2 %	2.0 %
3	2396.1463	242.94	237.43	**2.3 %**	**1.0 %**
4	1540.5865	102.49	102.43	0.1 %	2.0 %
6	534.9225	12.06	12.38	-2.7 %	6.0 %
7	2174.3146	208.33	203.99	**2.1 %**	**1.0 %**
8	1729.112	112.57	113.87	-1.2 %	1.5%
9	609.996	14.07	14.35	-2.0 %	5.0 %
10	2415.2228	217.58	223.02	**-2.5 %**	**1.0 %**
11	648.0378	15.98	16.08	-0.6 %	4.5 %

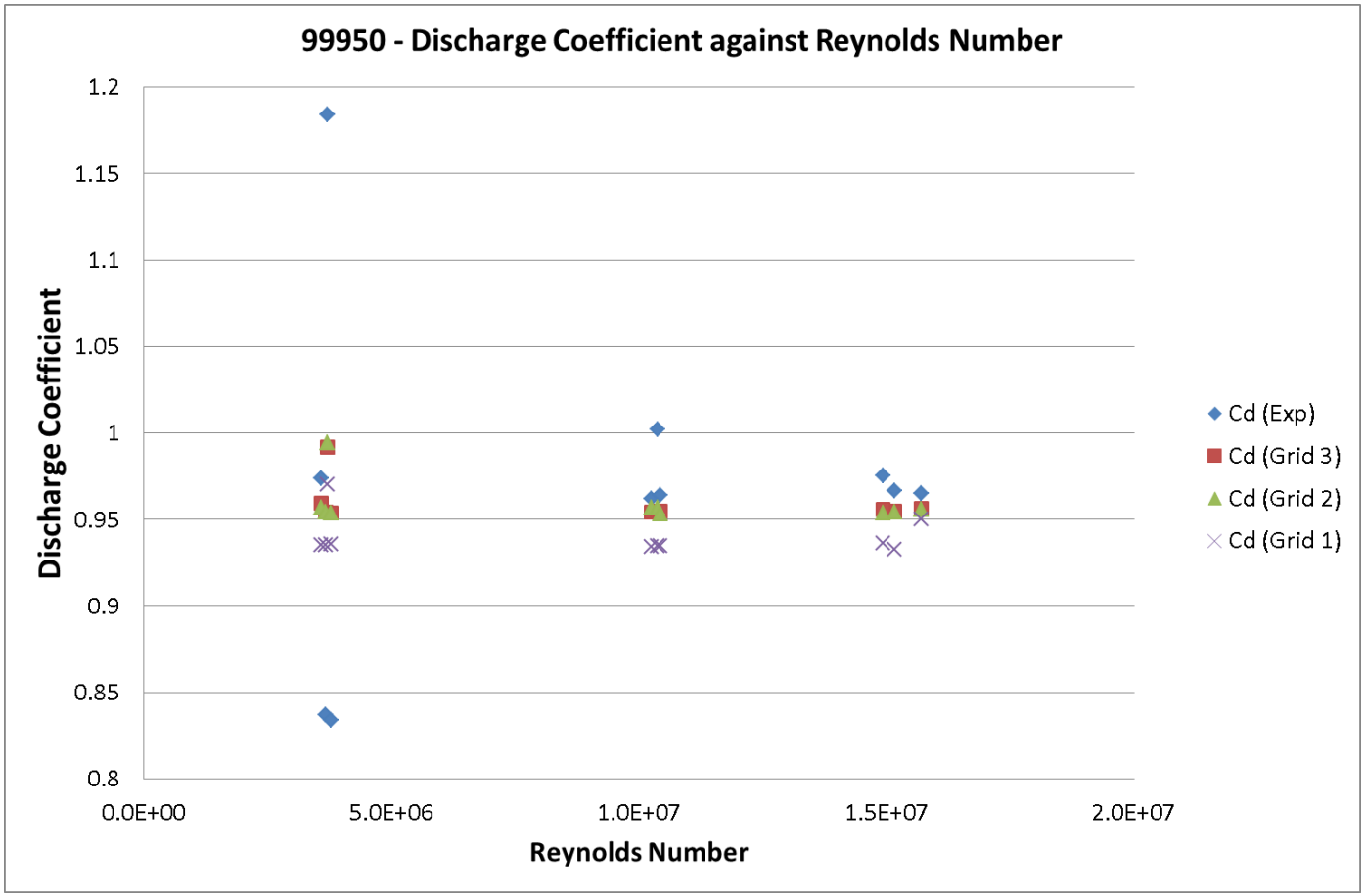
Results - CFD - 99985



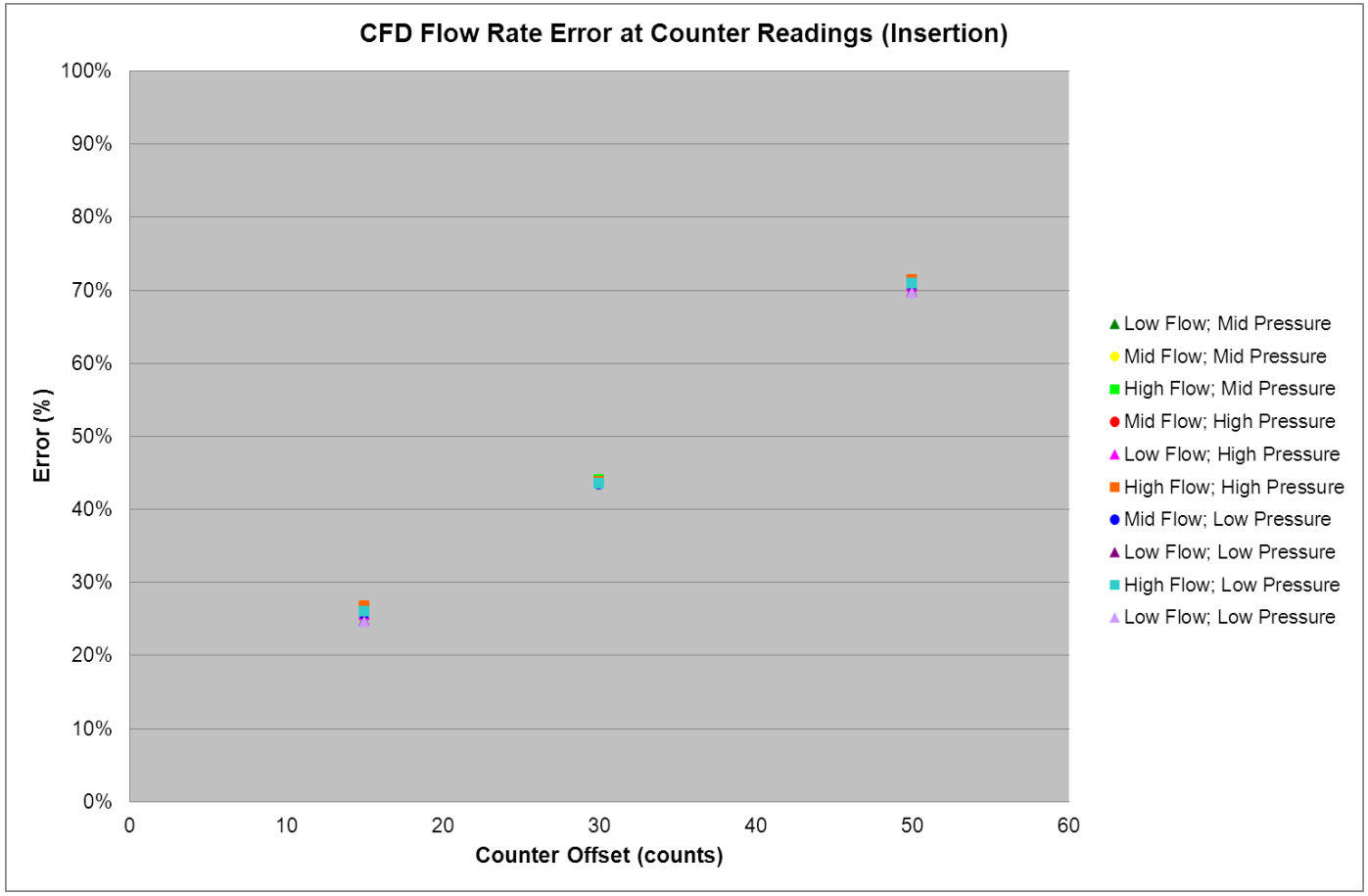
Results - CFD - 99950

Test	Actual Flow Rate (m^3/h)	Experimental DP (mbar)	CFD DP (mbar)	Error (%)	DP Measurement Uncertainty (%)
1	588.60	1.40	1.99	**-42 %**	**±40 %**
2	1619.6945	16.07	16.32	-1.6 %	±5 %
3	2459.8613	37.29	37.98	-1.9 %	±2.5 %
4	1564.3494	14.61	16.09	**-10 %**	**±6 %**
6	541.2844	1.85	1.91	-3.2 %	±40 %
7	2284.8572	33.42	34.28	**-2.6 %**	**±2.5 %**
8	1748.498	17.43	17.77	-2.0 %	±4 %
9	608.80	2.83	2.18	23 %	±30 %
10	2506.863	34.96	36.43	**-4.2 %**	**±2.5 %**
11	633.819	3.07	2.35	23 %	±30 %

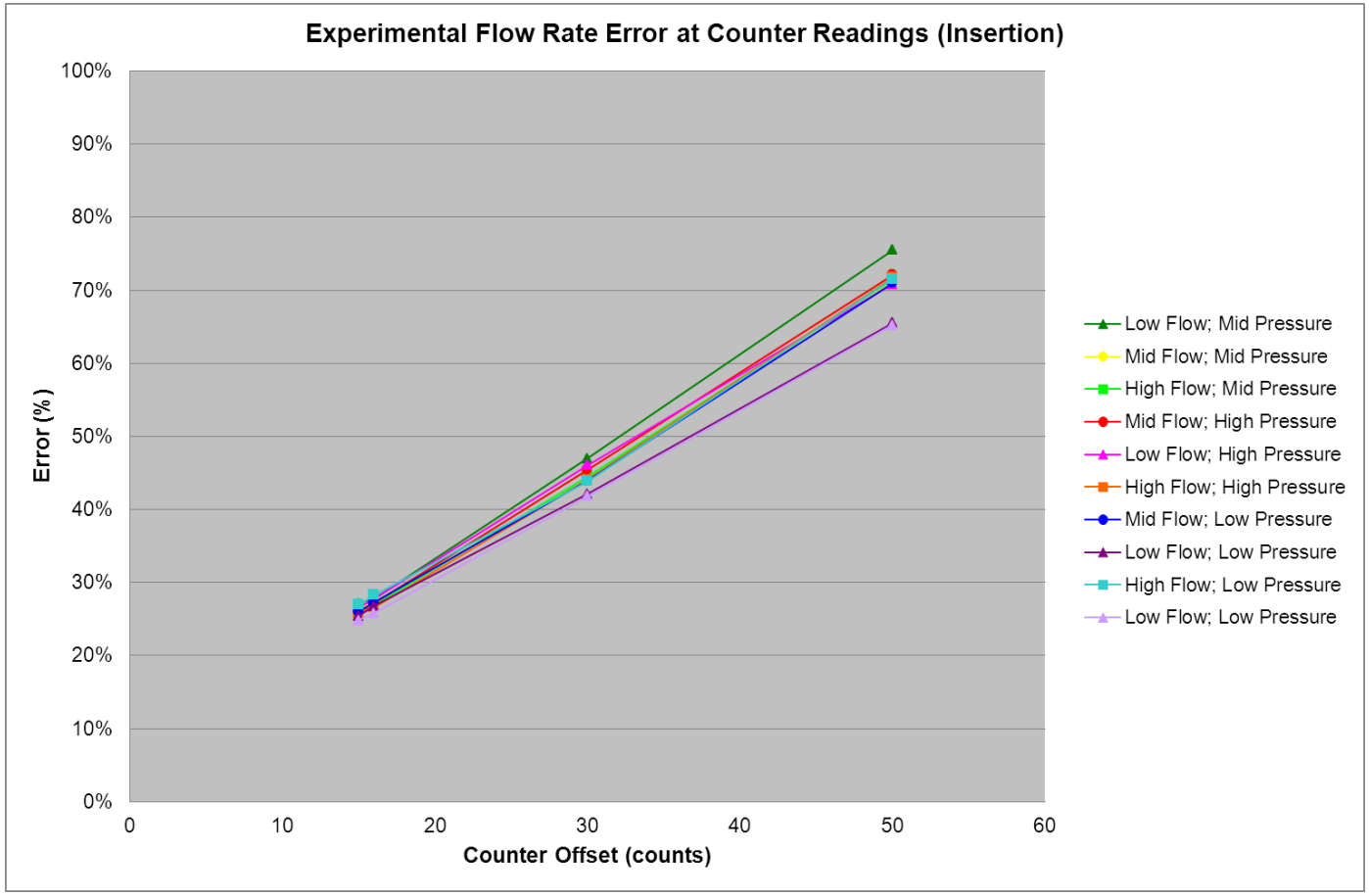
Results - CFD - 99950



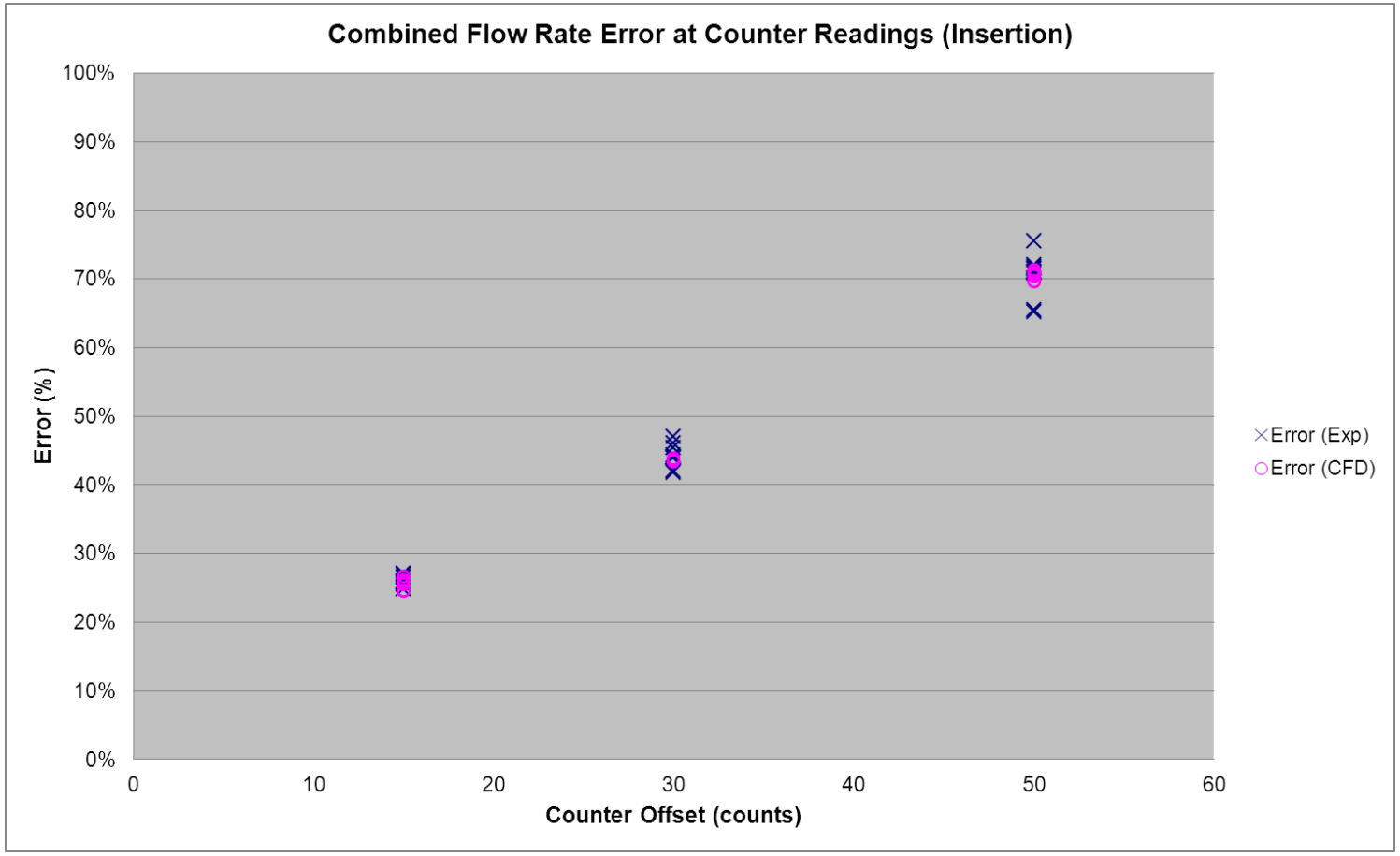
Results - CFD


CFD Flow Rate Error at Counter Readings (Insertion)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Error (%)
0
10
20
30
40
50
60
Counter Offset (counts)
Low Flow; Mid Pressure
Mid Flow; Mid Pressure
High Flow; Mid Pressure
Mid Flow; High Pressure
Low Flow; High Pressure
High Flow; High Pressure
Mid Flow; Low Pressure
Low Flow; Low Pressure
High Flow; Low Pressure
Low Flow; Low Pressure

Results - Experimental



Results - Combined



Results - Combined

Counter Reading	Experimental Error (%)		CFD Error (%)		Difference in Mean (% relative)
	Mean	Std. Dev.	Mean	Std. Dev.	
99985	26.1 %	0.7 %	25.7 %	0.7 %	-1.4 %
99950	70.6 %	**3.1 %**	70.6 %	0.6 %	0.0 %

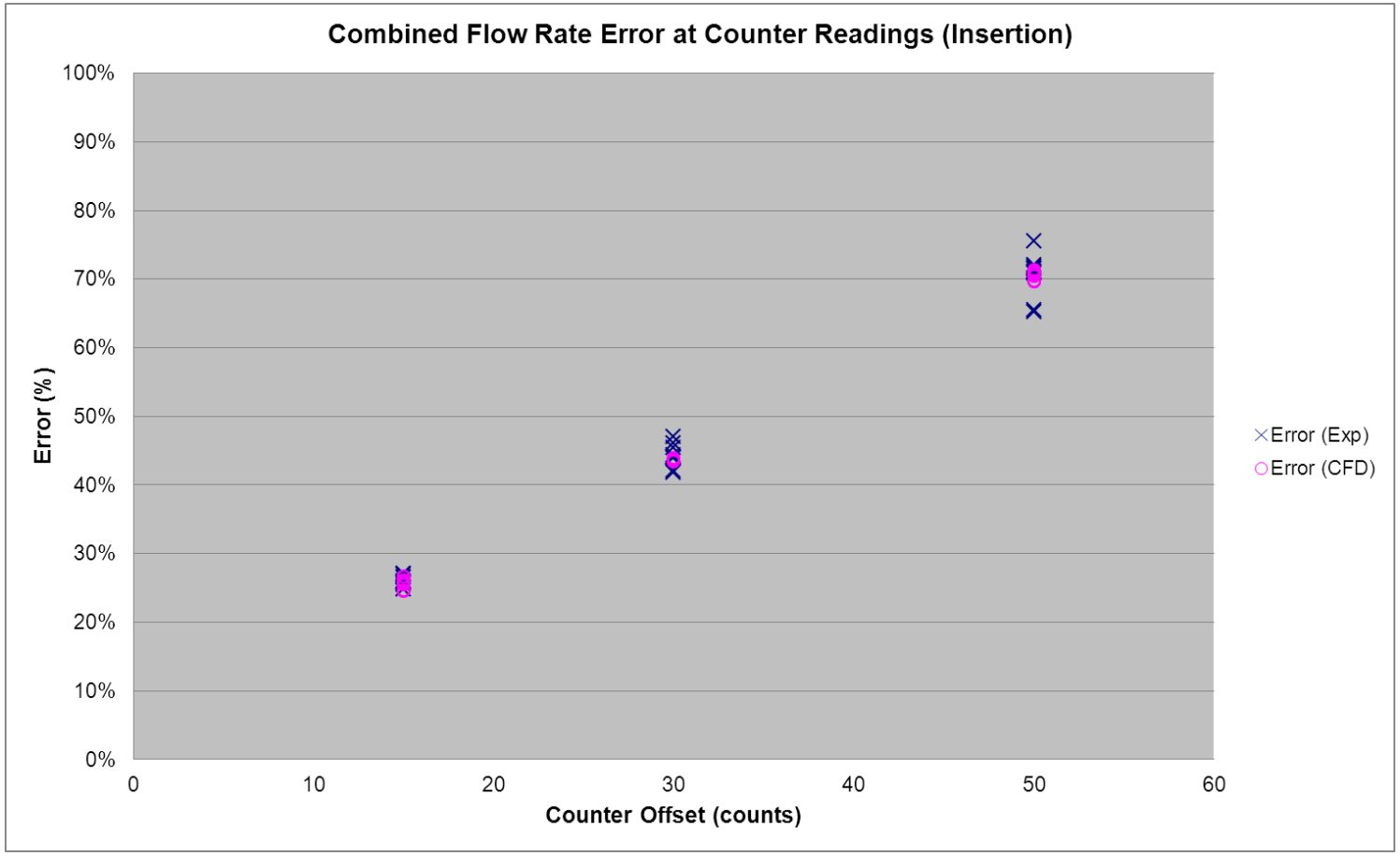
- High standard deviations at low DPs
  - Expected with higher uncertainty of DP measurement

Results - Combined

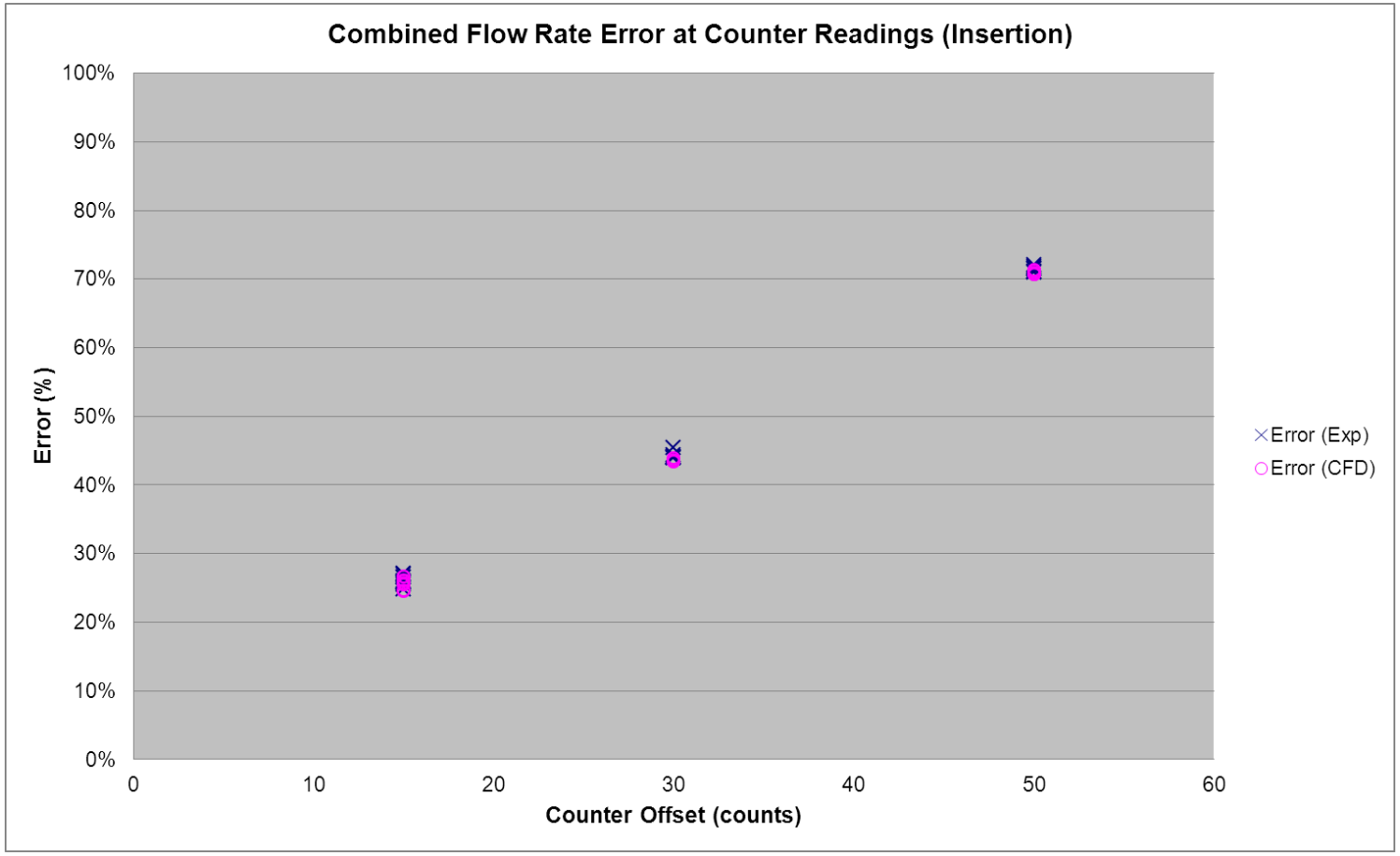
Counter Reading	Experimental Error (%)		CFD Error (%)		Difference in Mean (% relative)
	Mean	Std. Dev.	Mean	Std. Dev.	
99950 (All)	*70.6 %*	***3.1 %***	*70.6 %*	*0.6 %*	*0.0 %*
99950 (>10 mbar)	71.5 %	**0.4 %**	71.0 %	0.3 %	-0.7 %

- Excluding DPs below 10 mbar significantly reduces standard deviation
  - Demonstrates that the two data sets are more reliable above 10 mbar

Results - Combined



Results - Combined



Summary of First Error Period

- 21st July 2009 to 27th July 2010
- Counter reading of 99985 based on
  - ~31% step change in flow rate when the plate was inserted
  - 99885 values stamped on the carrier information plate
  - Pattern of contamination compared to physical measurements
- Mean error from on-site testing is 26.1 % (under-registration)
  - Standard deviation of 0.7 %
  - Supported by CFD (Mean 25.7 %; Standard deviation 0.7 %)
- Error is independent of process conditions
  - Single correction factor for period (1.353066)

Summary of Second Error Period

- 27th July 2010 to 10th August 2010
- Counter reading of 99950 based on
  - ~69% step change in flow rate when the plate location was corrected
  - 9995 value stamped on the carrier information plate
  - Interviews with mechanical operatives
- Mean error from on-site testing is 71.5 % (under-registration)
  - Standard deviation of 0.4 %
  - Supported by CFD (Mean 71.0 %; Standard deviation 0.3 %)
- Error is independent of process conditions
  - Single correction factor for period (3.506731)

Thank you. Any Questions?

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