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Technical Paper

DP Meter Verification System – Operator Field Results and Practical Use

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1 INTRODUCTION

Verifying the performance of any on line flow meter has its challenges. Standards are published in order to minimise the risk of unacceptable and unaccounted for measurement errors by offering clear and consistent requirements, specifications and guidelines in order to safeguard good meter performance. Operator specific guidelines are often used in addition to the standards. Site specific maintenance / inspection procedures are enforced in order to minimise the risk of financial exposure resulting from unforeseen or unpredictable problems which may cause an error or bias in meter system output.

The majority of standards, guidelines and procedures were written on the assumption that it is not possible to verify the meter system performance in situ without external cross checks (e.g., pay and check meters or mass balance checks) and scheduled spot checks (e.g., calibrations and inspections). Cousins et al [1] highlighted the inefficiencies of such traditional verification methods which are not only financially costly but are often performed unecessarily, are performed too late to save a significant mis-measurement or are inconclusive and unhelpful.

Ultrasonic meter diagnostic capabilities (as a methodology utilised to achieve verification) now at least feature in ultrasonic meter standards. The same cannot be said of DP meter diagnostic capabilities despite these being well known and repeatedly proven to industry. This paper details several case studies from a growing number of operators who have adopted the very latest advancements in DP meter self-verification; benefiting financially through operational efficiencies. The verification system in use is called ‘Prognosis’.

Field data from two 4” UK offshore orifice meters, two 16” onshore UK National Grid orifice meters, and an 8” UK offshore orifice meter are presented, showing full serviceability of the meters from the start of application. This is the typical verification system result, and its presence allows for a DP meter condition-based maintenance strategy.

Wet gas field data is presented from two (10” and 14”) UK offshore Venturi meters, two 20” UK onshore orifice meters and three (12”, 12” and 24”) UK offshore orifice meters. It is shown how the end user optimises the response of the system to wet gas flow; using the information as part of daily validation checks and as an indication of consistency or change in levels of liquid content. Furthermore, ConocoPhillips 4” orifice meter plunger lift wet gas flow data is presented. The verification system was also applied here as a liquid loading monitoring system.

Field data from three additional UK offshore (4”) orifice meters is shown. The verification system correctly indicated start up issues including liquid carry-over. Field data from two offshore 3” orifice meters is presented where the verification system identified DP errors inducing a significant mismeasurement of flow that would otherwise have gone unnoticed. The DP measurement errors were immediately detected by the diagnostic system and rectified avoiding pipeline partner disputes. Again, once these issues were rectified, the system could be used to develop a condition-based maintenance strategy, allowing for a reduction in needless meter and DP Transmitter maintenance activities.

Comparisons are made between the measured orifice meter Pressure Loss Ratio, the ‘Prognosis’ data fit prediction, the published ISO prediction, and the recently published Reader-Harris Pressure Loss Ratio prediction. It is confirmed that industry is now capable of predicting the pressure field through an orifice meter accurately enough to facilitate high resolution diagnostics, i.e. for un-calibrated orifice meters to have a capable verification system.

A brief review of the ‘Prognosis’ system is given in Section 12 (Appendix). For further details the reader should refer to the descriptions given by Steven [2, 3], Skelton et al [4] and Rabone et al [5].

2 EXAMPLE 1: 2 X 4” ORIFICE (0.5 BETA), OFFSHORE NORTH SEA

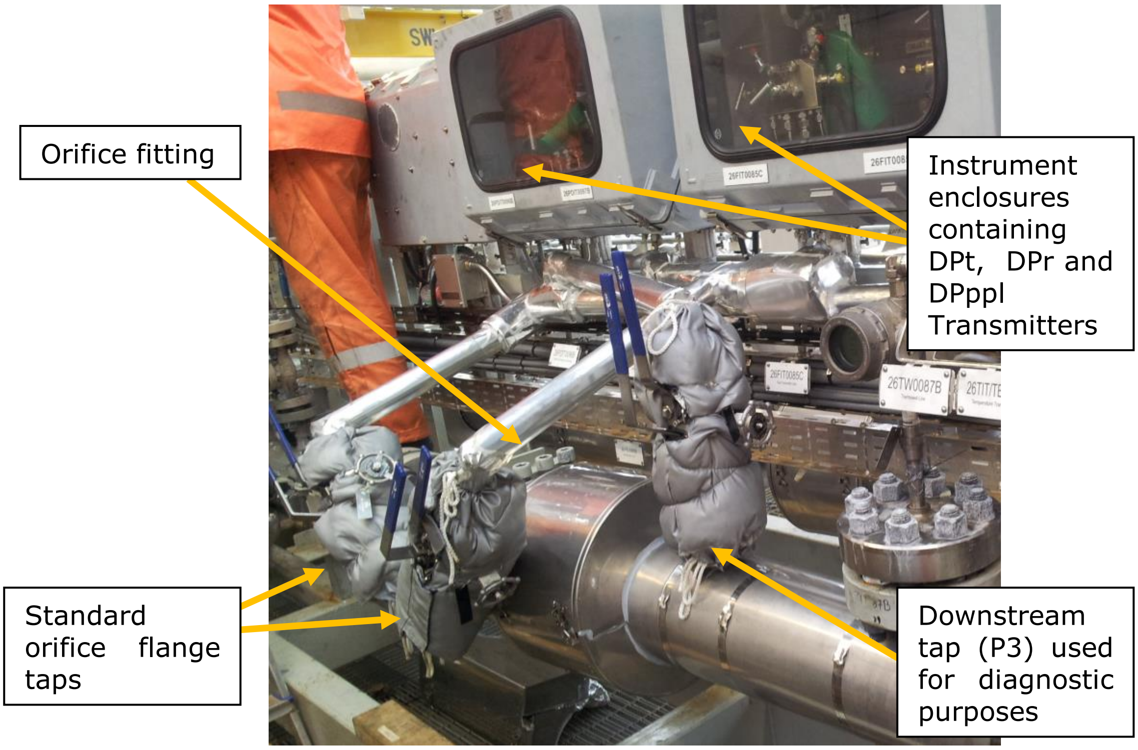
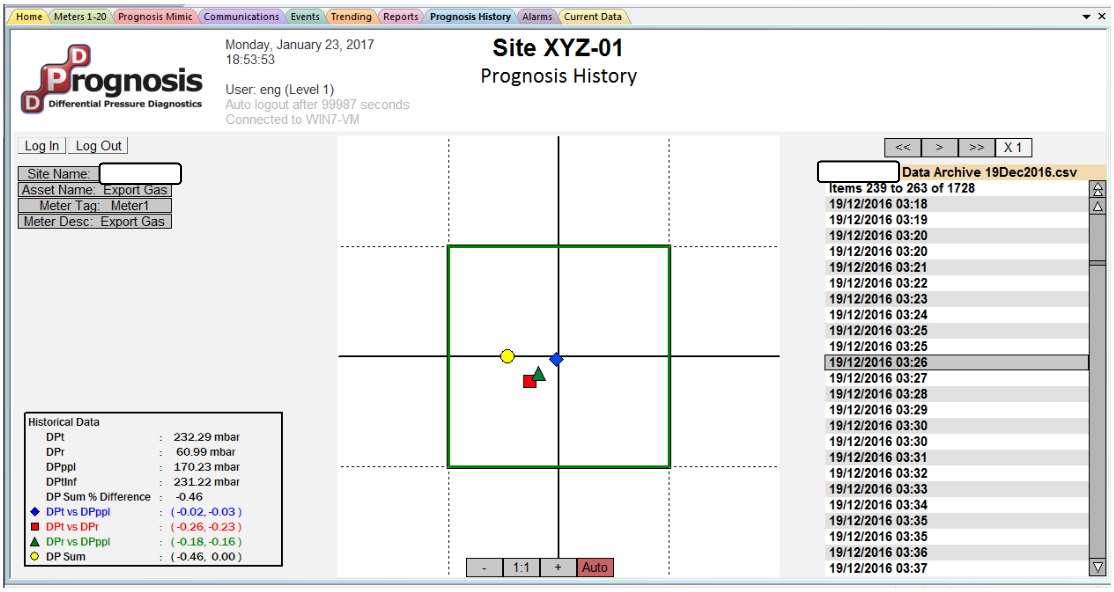


Figure 1 – Photograph of 4” orifice meter run with instrumentation

The ‘Prognosis’ DP Meter verification system was installed on two 4” orifice meters located on an FPSO in the central North Sea in early 2014. These meters measure gas which has been through two stages of separation and is the export gas to a major UK gas pipeline.

Figure 1 is a photograph of one of the meter runs showing its downstream tap location. Figure 2 shows a sample ‘Prognosis’ response (recorded 19th December 2016) from one of these 4”, 0.5β orifice meters. This is a screenshot from ‘Prognosis’ playing historical data recorded on a in-service meter. All points are in the box indicating that the meter is verified to be fully servicable. This is the typical result on a DP flow meter; most meters operate correctly most of the time. Figure 3 shows multiple data plotted from the same day, demonstrating the stability of the meter performance.



Monday, January 23, 2017
18:53:53

User: eng (Level 1)
Auto logout after 99987 seconds
Connected to WIN7-VM

Site XYZ-01
Prognosis History

Site Name: [redacted]
Asset Name: Export Gas
Meter Tag: Meter1
Meter Desc: Export Gas

Historical Data

	DPt	:	232.29 mbar
	DPr	:	60.99 mbar
	DPppl	:	170.23 mbar
	DPtInf	:	231.22 mbar
	DP Sum % Difference	:	-0.46
◆	DPt vs DPppl	:	(-0.02, -0.03)
■	DPt vs DPr	:	(-0.26, -0.23)
▲	DPr vs DPppl	:	(-0.18, -0.16)
●	DP Sum	:	(-0.46, 0.00)

[redacted] Data Archive 19Dec2016.csv

Items 239 to 263 of 1728
19/12/2016 03:18
19/12/2016 03:19
19/12/2016 03:20
19/12/2016 03:20
19/12/2016 03:21
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19/12/2016 03:33
19/12/2016 03:34
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19/12/2016 03:35
19/12/2016 03:36
19/12/2016 03:37

Figure 2 - Example ‘Prognosis’ response indicating good meter performance

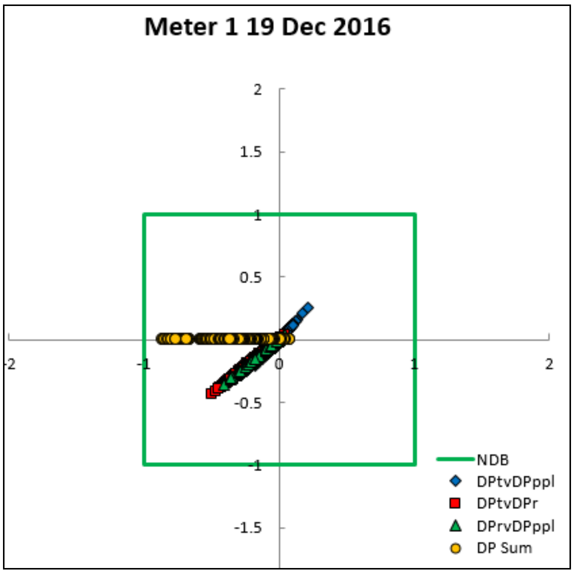


Figure 3 – Example multiple data plot indicating good meter performance

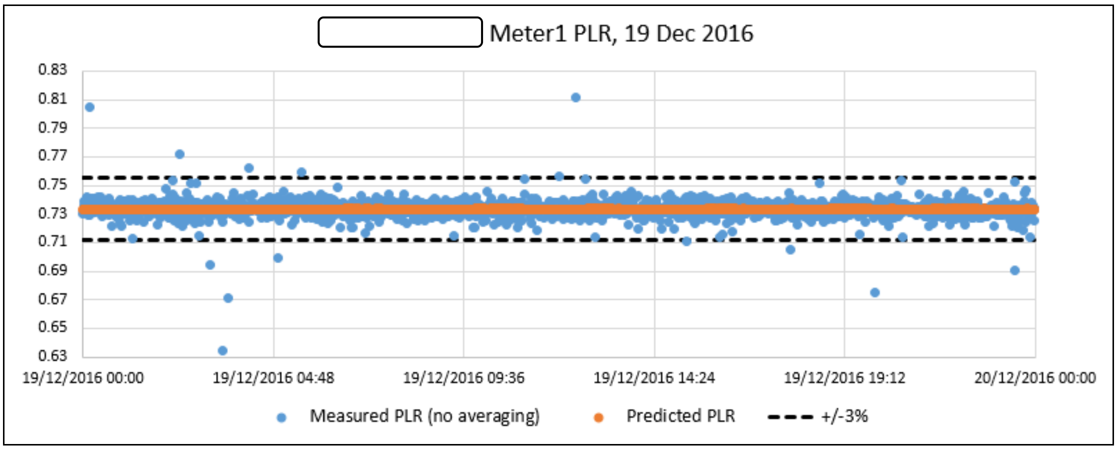


Figure 4 – Example measured versus predicted PLR over one day (no averaging applied)

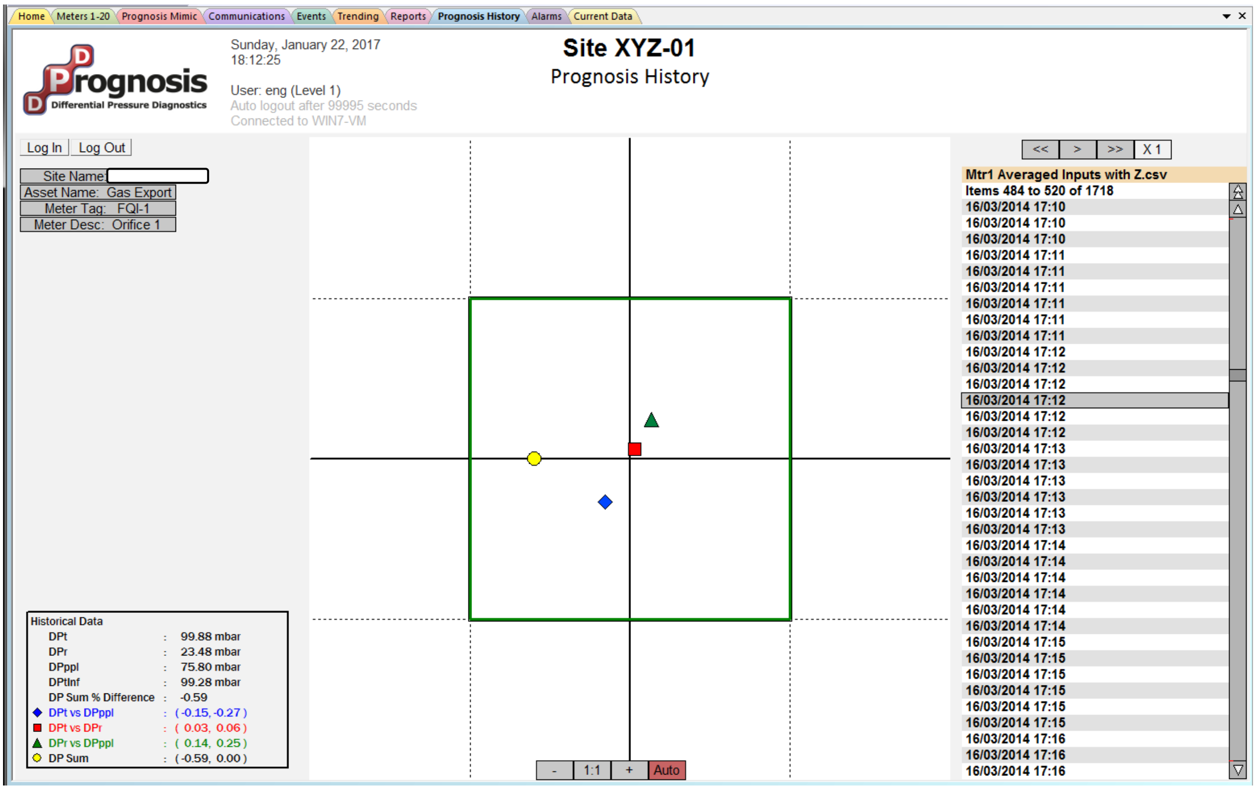
Flow meters inevitably encounter periodoic flow fluctuations. Such transient flow affects could naturally cause ‘Prognosis’ to momentarily register a possible event. However, such false alarms are easily dealt with in practice by applying suitable sensitivity, ‘low flow cut off’, and ‘alarm delay’ settings. Figure 2 and Figure 3 data has the ‘averaging’ sensitivity setting applied. Figure 4 shows sample historical data from the same orifice meter with no ‘averaging’ applied, where one of the seven diagnostic checks (PLR, i.e. coordinate y1) is plotted vs. time. Periodically there are results outside of the normal results; in this case >3% from prediction. With the ‘averaging’ sensitivity setting applied, false alarms are easily avoided.

These results assure the end user that the orifice meter is fully serviceable and does not require maintenance. The operator of these meters has successfully used ‘Prognosis’ data as part of a justification for reducing maintenance and inspection frequencies relating to both the orifice plates and the DP transmitters as detailed in Table 1. This is a reduction in the associated maintenance activities of 57% overall. The corresponding estimated financial savings is £28,000 per year, every year.

Table 1– Reduction in Maintenance Activities

Device	Test	Previous Frequency	New Frequency
DP Transmitter	Zero Check	Monthly	3 Monthly
DP Transmitter	Offshore verification	3 Monthly	6 Monthly
DP Transmitter	Onshore footprint calibration	6 Monthly	3 Yearly
Orifice Plate	Inspection	3 Monthly	6 Monthly

3 EXAMPLE 2: 2 x 16” ORIFICE, ONSHORE UK NATIONAL GRID OFFTAKE



Sunday, January 22, 2017
18:12:25

User: eng (Level 1)
Auto logout after 99995 seconds
Connected to WIN7-VM

Site XYZ-01
Prognosis History

Site Name:
Asset Name: Gas Export
Meter Tag: FQI-1
Meter Desc: Orifice 1

Historical Data

	DPt	:	99.88 mbar
	DPr	:	23.48 mbar
	DPppl	:	75.80 mbar
	DPtInf	:	99.28 mbar
	DP Sum % Difference	:	-0.59
◆	DPt vs DPppl	:	(-0.15, -0.27)
■	DPt vs DPr	:	(0.03, 0.06)
▲	DPr vs DPppl	:	(0.14, 0.25)
○	DP Sum	:	(-0.59, 0.00)

Mtr1 Averaged Inputs with Z.csv
Items 484 to 520 of 1718
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16/03/2014 17:16

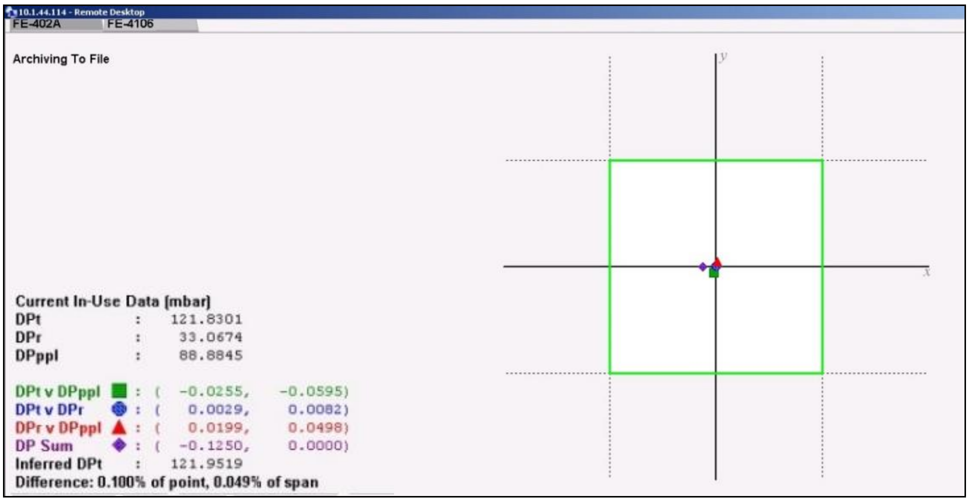
Figure 5 – Example National Grid orifice meter ‘Prognosis’ response (Meter 1)

The ‘Prognosis’ DP Meter validation system was applied to 2 x 16” orifice plates (0.475β) at a UK National Grid offtake. On both meter runs, the downstream tap was located slightly further upstream than the ideal location of 6D downstream of the plate. As the ‘Prognosis’ downstream pressure tap location correction tool is applicable to > 6D, the standard procedure in such cases is to ascertain a baseline by utilising the ‘Prognosis’ zeroing option during system commissioning. This is analogous with ultrasonic meter diagnostic system standard practice of taking a fingerprint of the diagnostic suite response on initial start up for use as a baseline. Appropriate ‘Z Factors’ Z = 0.008 for meter 1 and Z = 0.015 for meter 2 were applied[1]. Figure 5 shows historical data from Meter 1 from 16th March 2014. Meter 2 results were similar. No alarms are present indicating that the meters are serviceable and no maintenance is required.

The UK National Grid (like other meter users) has different flow metering uncertainty budgets for different flow ranges. Therefore, National Grid chose to utilise the system’s option to automatically select different diagnostic sensitivities at different flow rates. For example, a very low flow rate produces low DPs with associated higher DP reading uncertainty. This is analogous with AGA 9 expanding the allowable uncertainty of an as found ultrasonic meter at low flows. Reducing the diagnostic sensitivity at low flows is another example of how industry should have no concern about false alarms.

4 EXAMPLE 3: 8” ORIFICE, OFFSHORE SOUTHERN NORTH SEA

The ‘Prognosis’ DP Meter validation system was applied to an 8” orifice meter (0.5β) located offshore in the Southern North Sea. The meter measures unprocessed natural gas. The sensitivity of the verification system’s diagnostic checks were at the ‘default’ settings. The operator chose to view live the average result over the preceeding 30 seconds, while the system logged data every 20 seconds. A delay of 60 seconds was chosen for registering an alarm. That is, the alarm had to be present for one minute before the operator was notified. This is another example of how the operator can easily avoid false alarms. Figure 6 shows a screenshot of the ‘Prognosis’ output during commissioning. The meter is shown to be serviceable and the operator is assured no maintenance is required.



```
Archiving To File

Current In-Use Data [mbar]
DPt              :    121.8301
DPr              :     33.0674
DPppl            :     88.8845

DPt v DPppl  ■ : (   -0.0255,    -0.0595)
DPt v DPr    ● : (    0.0029,     0.0082)
DPr v DPppl  ▲ : (    0.0199,     0.0498)
DP Sum       ◆ : (   -0.1250,     0.0000)
Inferred DPt     :    121.9519
Difference: 0.100% of point, 0.049% of span
```

Figure 6 – Example 8” orifice meter ‘Prognosis’ response December 2013

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[1] For details of how the ‘Z Factor’ is defined and used the reader should refer to descriptions given by Skelton [4] and Ayre [8].

Figure 7 shows a plot of multiple results over a period of 24 hours recorded approximately 1 month after commissioning. This shows there has been no significant change in the meter's performance. In this particular case, the operator was specifically interested to see if the system would indicate any liquid presence in the gas. The verification system's response assured them that this was indeed dry gas (with no liquid present). Again, this is the most common response, as most meters operate correctly most of the time.

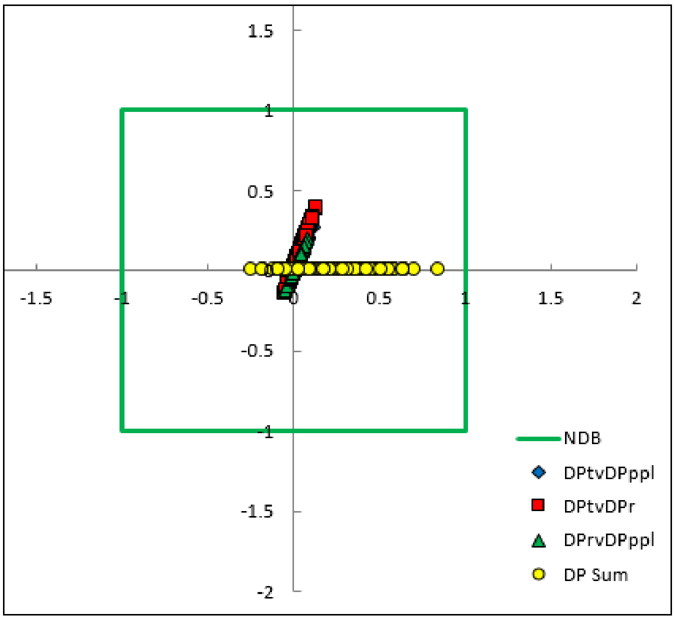


Figure 7 – Multiple 'Prognosis' 24-hour data plot, January 2013

The meter operator receives daily reports from the DP meter validation software automatically via email providing a quick and reliable 'health check' on the meter performance. If any issues occur causing a potential error in reported flow rate, the operator has the information at hand to be able to investigate the issue promptly.

5 EXAMPLE 4: 10" and 14" VENTURI METERS, WET GAS

5.1 10" Venturi Meter

Two Venturi meters (both 0.4β), located on an offshore Gas Production Platform in the East Irish Sea are measuring unprocessed wet gas from two different fields. Both were calibrated in dry gas prior to installation. These calibrations included setting the Venturi meter baseline characteristics (as functions of Reynolds Number), this is analogous to ultrasonic meter calibrations setting their diagnostic 'fingerprint'.

With the Venturi meter gas flow diagnostic baseline pre-set, the system can monitor the meter as soon as it is in use. Figure 8 shows a plot of multiple data collected over a 24 hour period from the 10" Venturi meter. As expected, the data displays a typical 'wet gas response'. As can be seen in the Figure 8 left hand plot, and as expected for a Venturi meter (see Ayre [8]), the PLR (pressure loss ratio) is the most sensitive of the diagnostics to the particular problem of wet gas. This is (for well understood theoretical reasons) different to orifice meters as will be made evident in Sections 6, 7 and 8.

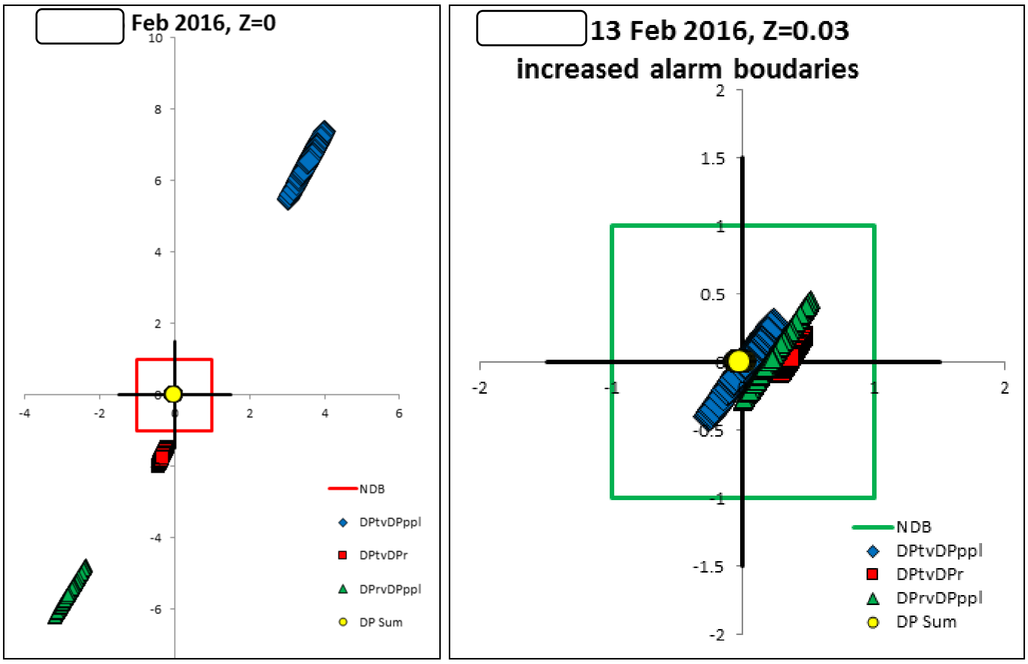


Figure 8 - Plot of multiple data over a 24 hour period (10” meter), wet gas response

A suitable ‘Z Factor’ was suggested to the operator by the verification system and entered. Sensitivity settings were also slightly reduced from the default values to accommodate the fact that wet gas conditions often cause an increase in DP reading standard deviations. Figure 8 right hand plot shows the same data, now with the system’s suggested ‘Z Factor’ of 0.03 and the modified sensitivity settings applied. A change in liquid loading will cause the points to again shift outside the box. The operator will therefore subsequently be alerted should there be a significant change in liquid loading or should other problems occur.

5.2 14” Venturi Meter

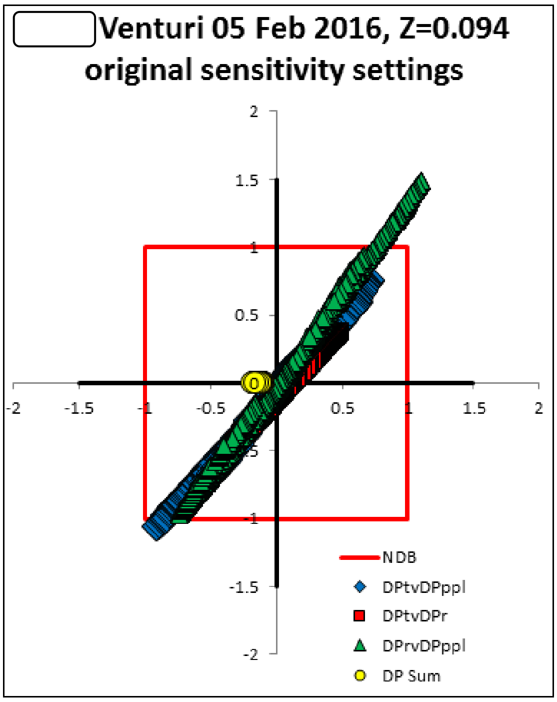


Figure 9 – Multiple data plot of ‘Prognosis’ results over a 24 hour period

Figure 9 shows multiple results over a 24 hour period for the 14" Venturi meter in wet gas service with a suitable 'Prognosis' suggested 'Z Factor' applied. The original 'dry gas' sensitivity settings are applied prior to being modified to allow for the naturally unstable nature of the wet gas flow. Figure 10 shows the corresponding DPs trended over the same 24 hour period. The three DPs are synchronised as required by physical law.

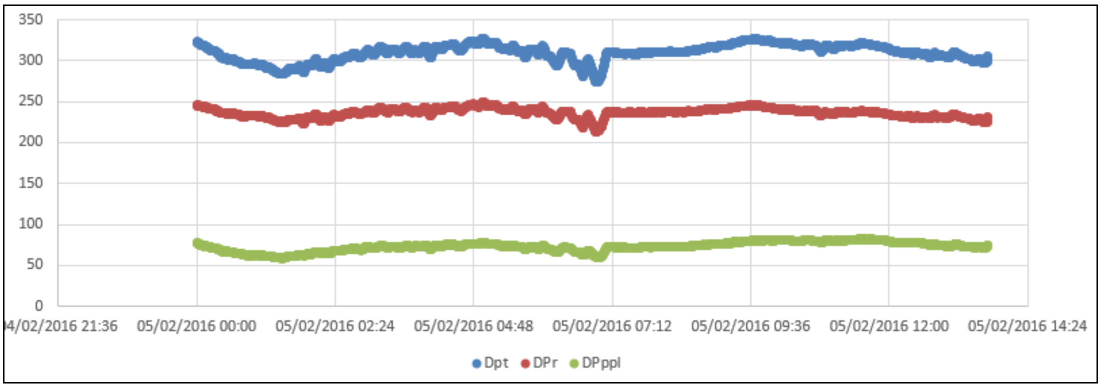


Figure 10 – Three DPs trended over a 24 hour period

Figure 11 shows a multiple data plot of 'Prognosis' results over a 24 hour period, 5 weeks later. The primary DP integrity check implies no DP transmitter problem, but high variance is observed in the other diagnostic parameters. The baseline adjustment (Z Factor) previously identified is no longer suitable.

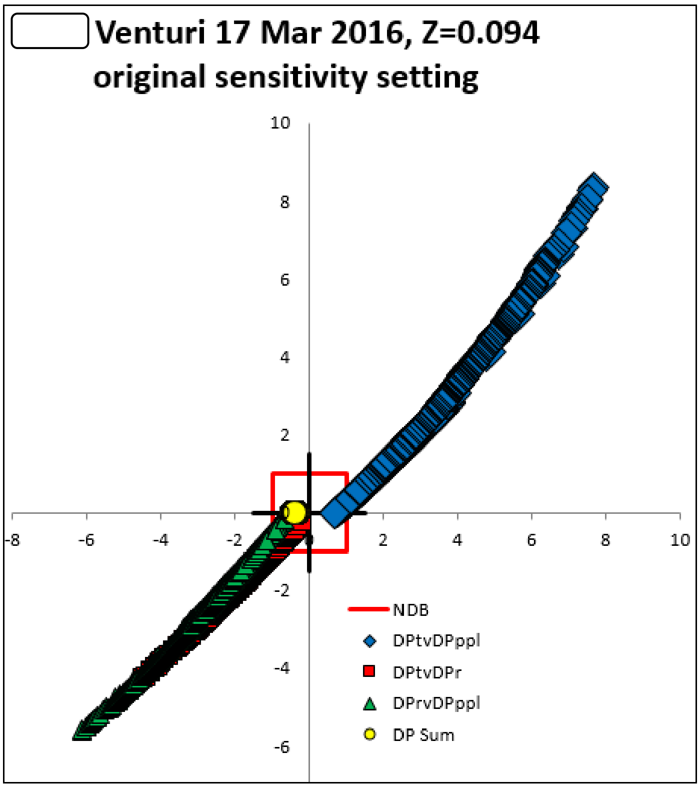


Figure 11 – Multiple results over a 24 hour period where high variation is observed

Figure 12 shows the three DPs being trended during this time. The DPt and DPppl readings are increasing and decreasing synchonously, whereas the DPr is more stable in comparison. Such a response is indicative of a blocked impulse line. The communal impulse line to the DPt and DPppl is the inlet pressure tap's impulse line. It is that which is blocked. This result shows that the traditional DP read is erroneous, and therefore the reported meter flow rate, and any resultant wet gas corrected flow rate, is not guaranteed to be correct.

Further observations of 'Prognosis' show periods of impulse line blockages. The validation system offers the operator valuable real time and historical play back information about the process, the condition of the impulse lines, and therefore the integrity of the flow rate prediction, which is visible in real time from the Control Room. Without the validation system, the operator would be running the system blind and unaware of these measurement issues.

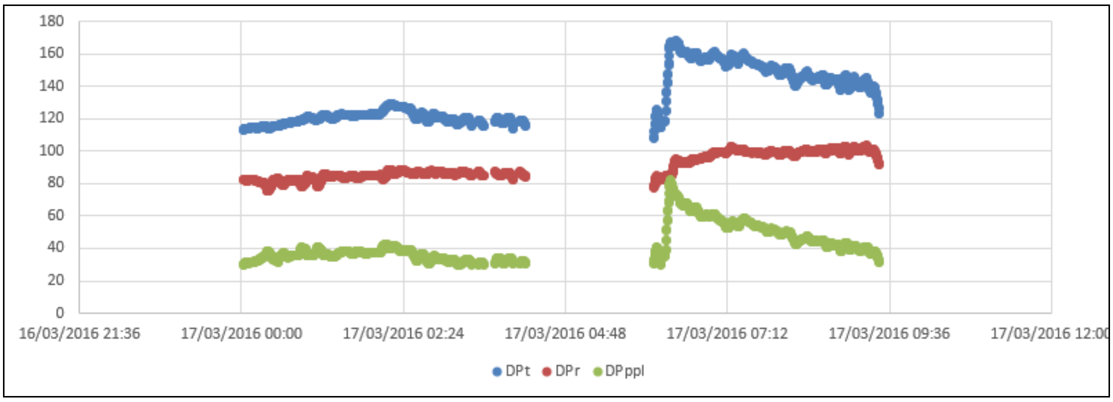
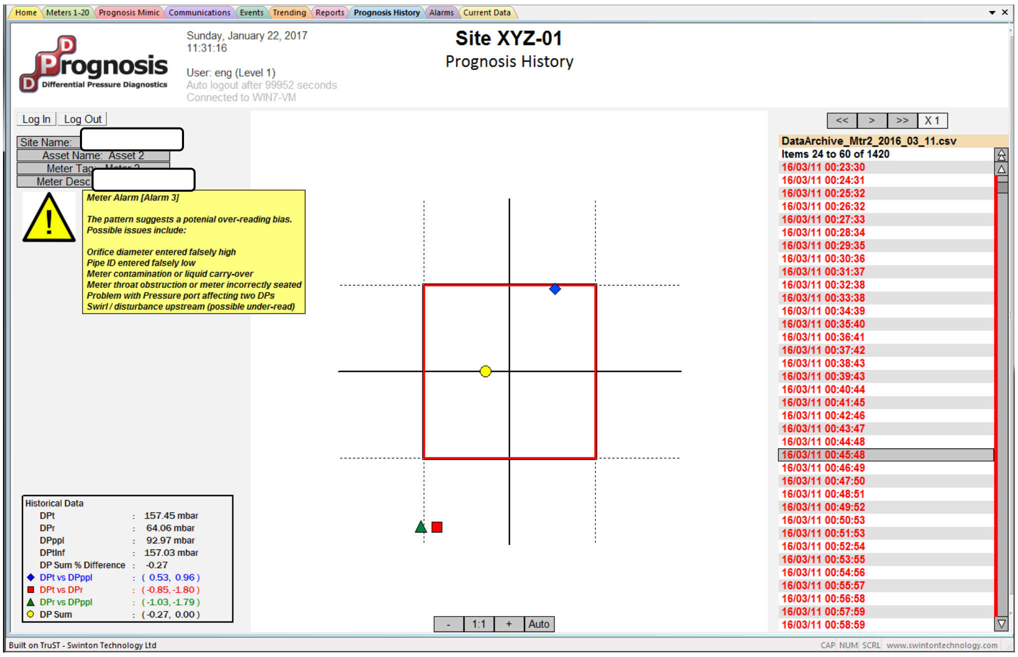


Figure 12 Three DPs trended over a 24 hour period (17th March 2016)

6 EXAMPLE 5: 2 x 20" ORIFICE METERS, ONSHORE GAS TERMINAL

The operator of a UK onshore gas terminal applied the DP Meter verification system to two new, 0.65β orifice meters in order to verify good meter performance and reduce associated maintenance activities.



Sunday, January 22, 2017
11:31:16

User: eng (Level 1)
Auto logout after 99952 seconds
Connected to WIN7-VM

Site XYZ-01
Prognosis History

Site Name: [redacted]
Asset Name: Asset 2
Meter Tag: [redacted]
Meter Desc: [redacted]

Meter Alarm [Alarm 3]

The pattern suggests a potenial over-reading bias.
Possible issues include:

Orifice diameter entered falsely high
Pipe ID entered falsely low
Meter contamination or liquid carry-over
Meter throat obstruction or meter incorrectly seated
Problem with Pressure port affecting two DPs
Swirl / disturbance upstream (possible under-read)

Historical Data

DPt	:	157.45 mbar
DPr	:	64.06 mbar
DPppl	:	92.97 mbar
DPtInf	:	157.03 mbar
DP Sum % Difference	:	-0.27
◆ DPt vs DPppl	:	(0.53, 0.96)
■ DPt vs DPr	:	(-0.85, -1.80)
▲ DPr vs DPppl	:	(-1.03, -1.79)
○ DP Sum	:	(-0.27, 0.00)

DataArchive_Mtr2_2016_03_11.csv
Items 24 to 60 of 1420
16/03/11 00:23:30
16/03/11 00:24:31
16/03/11 00:25:32
16/03/11 00:26:32
16/03/11 00:27:33
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16/03/11 00:55:57
16/03/11 00:56:58
16/03/11 00:57:59
16/03/11 00:58:59

Figure 13 – Typical system response

The initial system response to the performance of the on-line meter indicated a problem. The response (showing an alarm) was extremely steady and repeatable which is uncharacteristic of wet gas flow. Figure 13 shows an example of historical data recorded at the beginning of 2016. The first ‘possible cause’ of alarm offered by the system is incorrect geometry in use. It was confirmed that there was no error in meter geometry in use, therefore the problem was most likely due to a small relatively constant amount of liquid present in the gas. This has subsequently been advised by the Processs engineers to be the case and was the next ‘possible cause’ of alarm offered by the system.

A suitable ‘Z Factor’ for each meter was offered by the system which would adjust the expected ‘baseline’ meter performance to accommodate the observed process conditon. Figure 14 shows two plots of the same set of data recorded over a 24 hour period. The left hand graph has original (default) baseline settings, the right hand graph includes a ‘Z Factor’ input of 0.017 (suggested by the verification system) which adjusts the expected meter performance to allow for the known problem of that amount of trace liquid presence.

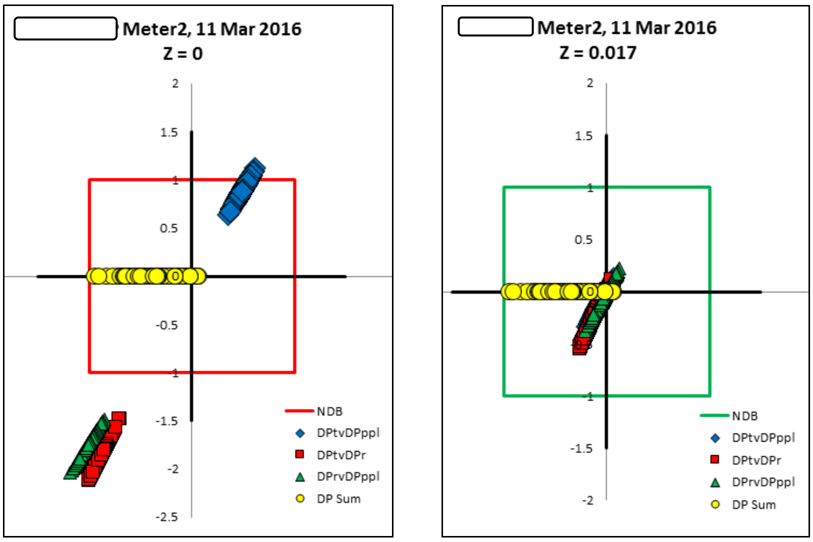


Figure 14 – Multiple data plots (24 hour period). Left: Original baseline settings, Right: Baseline adjusted to allow for known problem of trace liquid

This ‘Z Factor’ is only valid at the specific liquid loading at the time it was set. If the liquid loading subseqently increases or decreases this factor will be too small or too large respectively. The points will again move outside of the box, thereby indicating a change in conditions, and whether the change is increasing or decreasing liquid loading. The operator may now be confident that if the amount of liquid increases or decreases it will be obvious from the ‘Prognosis’ result.

As discussed in previous sections, it is possible for the end user to adjust sensitivity and alarm settings which will inhibit alarms due to DP uncertainty at very low flows. In this case, as the measured DPr and DPppl do not exceed (and are not expected to exceed) 200mbar and 150mbar respectively the operator decided to range these transmitters in order that higher sensitivity to real problems be retained at lower flows. It is best practice and important to select DP transmitter ranges that are appropriate to the application. Properly ranged DP transmitters minimize the flow rate prediction uncertainty, and maximise both the meter’s flow range and the range covered by the verifcation system.

7 EXAMPLE 6: 12” and 24” ORIFICE, OFFSHORE WET GAS DATA

7.1 12” Orifice Separator Meter

A North Sea operator applied the ‘Prognosis’ verification system to a 12” (0.686β) orifice meter measuring gas from a separator, installed on a gas condensate field development. The operator suspected there would be condensate remaining in the gas following separation. They wished to use the ‘Prognosis’ system to confirm the presence of liquids, to monitor for significant changes in the level of liquids, and to monitor the health of DP Transmitters and the general metering system. The initial results in 2017 confirmed the presence of liquid. Figure 15 is a multiple data plot of ‘Prognosis’ results from 1st July 2017; the pattern and distribution of the results is characteristic of orifice wet gas flow. The operator also uses historical trending to compare the three DPs and check that they are tracking each other. This together with the ‘DP Sum’ integrity check offers an instant and on going validation of the health of the secondary instrumentation. ‘Prognosis’ is part of the daily validation pocedures on this metering system.

The operator confirmed that according to modelling, the gas contained 4-5% condensate on mass. In order to monitor for significant changes in liquid loading, the operator chose to ‘zero’ the system’s response. Figure 16 shows the ‘zeroed’ response, any subsequent alarm will be an indication of either an increase or decrease in liquid loading.

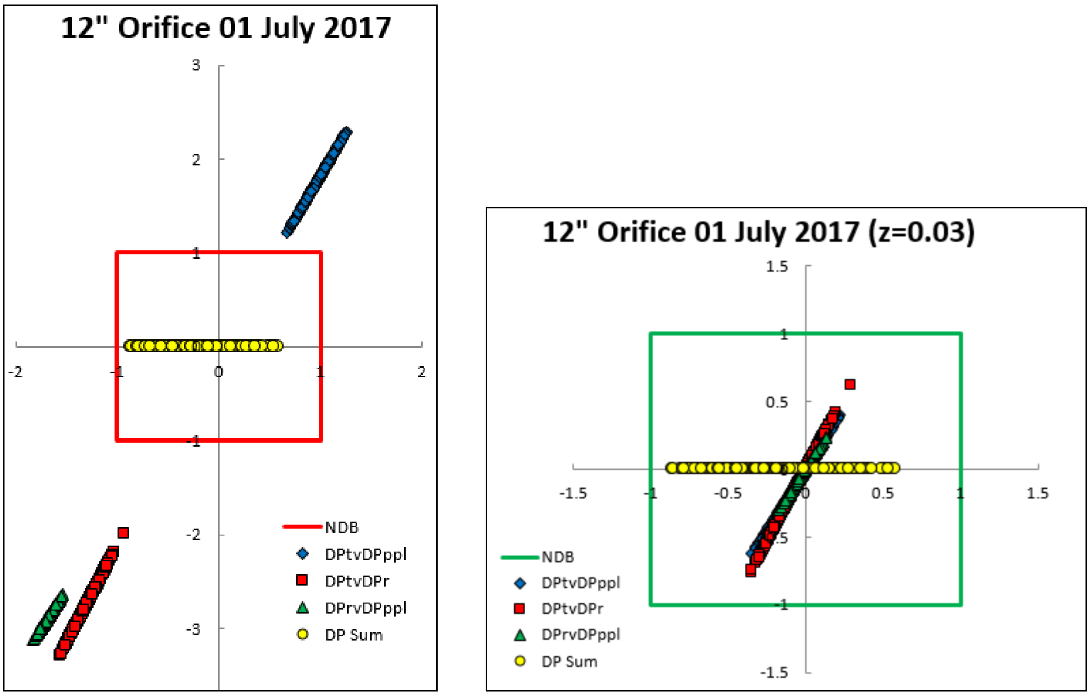


Figure 15 (left) – 12” orifice, non-zeroed wet gas response. Figure 16 (right) – 12” orifice, zeroed wet gas response.

7.2 12” Orifice Wellhead Test Separator Meter

A North Sea operator has an offshore development with seven wells feeding into a test separator. The ‘Prognosis’ validation system is used on the 12”, 0.388β orifice meter on the gas output of this separator. The system is used to observe the meter response as different wells come on line (one at a time). No ‘Z Factor’ is applied as it is more useful to the metering team and the process engineers to see the 'raw' result and compare results between well flows as an indication of comparative 'wetness'. The level of condensate at each individual well is not known as no modelling has been performed. The information provided by 'Prognosis' is therefore seen as very valuable when matching the well tests with the fluid coming out of a High Pressure Separator after the wells have been comingled (see Section 7.3).

Figure 17 shows recent data recorded during testing of three different wells. From left to right, wells 1, 9 and 4 all indicate wet gas flow with respective increasing liquid loading.

At the time of installation, there was not sufficient I/O capacity in the flow computers to accommodate two additional DP Transmitters. Therefore, the 'permanent pressure loss DP' (DPppl) is measured and the 'recovered DP' (DPr) is inferred (see equation 1). It is not possible to perform the 'DP Sum' integrity check in this case hence it is not shown. At the time, it was also company policy to install two stacks of (high and low) 'traditional' meter DPs to act as 'pay' and 'check' on the traditional meter DP. This policy was for the simple reason that historically, there did not exist any on line validation of DP integrity. The operator now agrees that the DP integrity checks offered by the 'Prognosis' validation system when three DPs are measured are (for the same number of transmitters) far more valuable and conclusive than installing 'pay and check' transmitter stacks.

The operator's global specifications now recommend the use of the verification system (with all three DPs measured) for any custody transfer DP device.

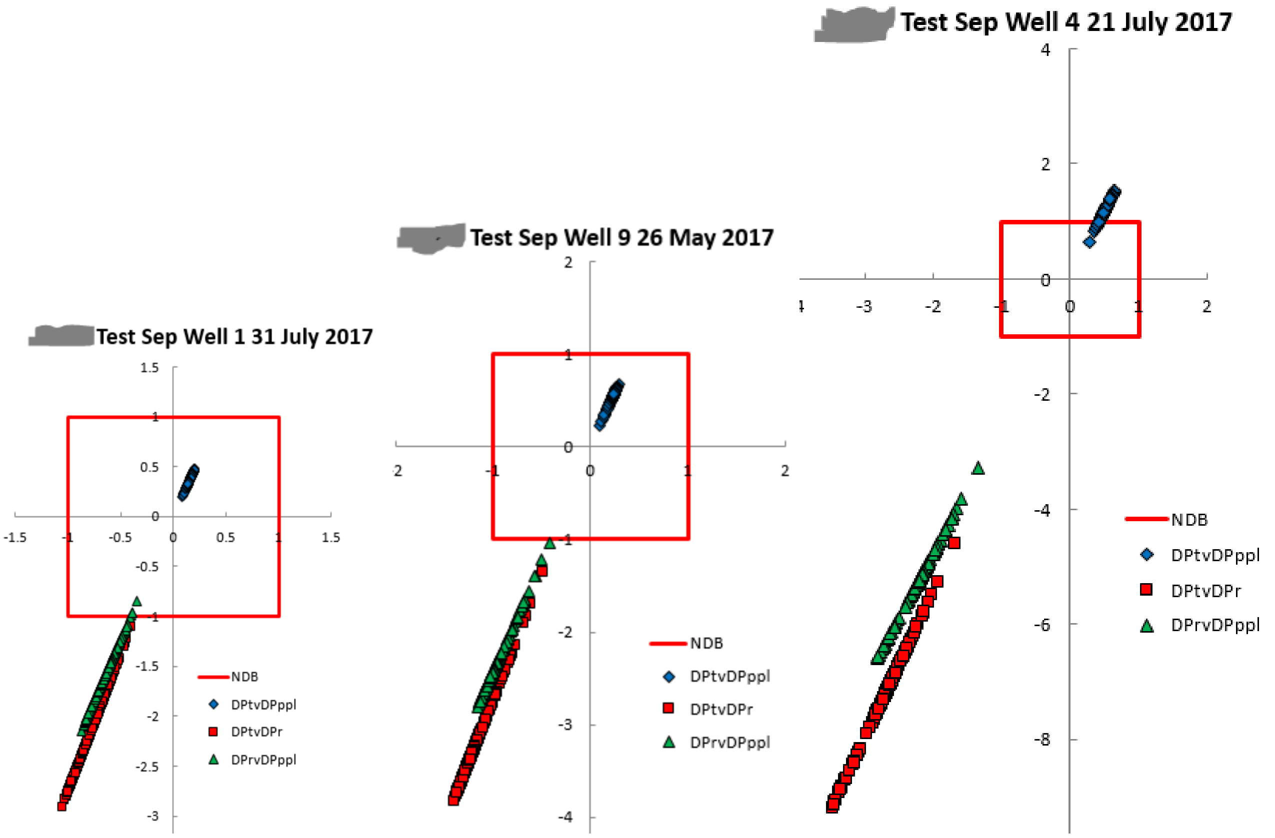


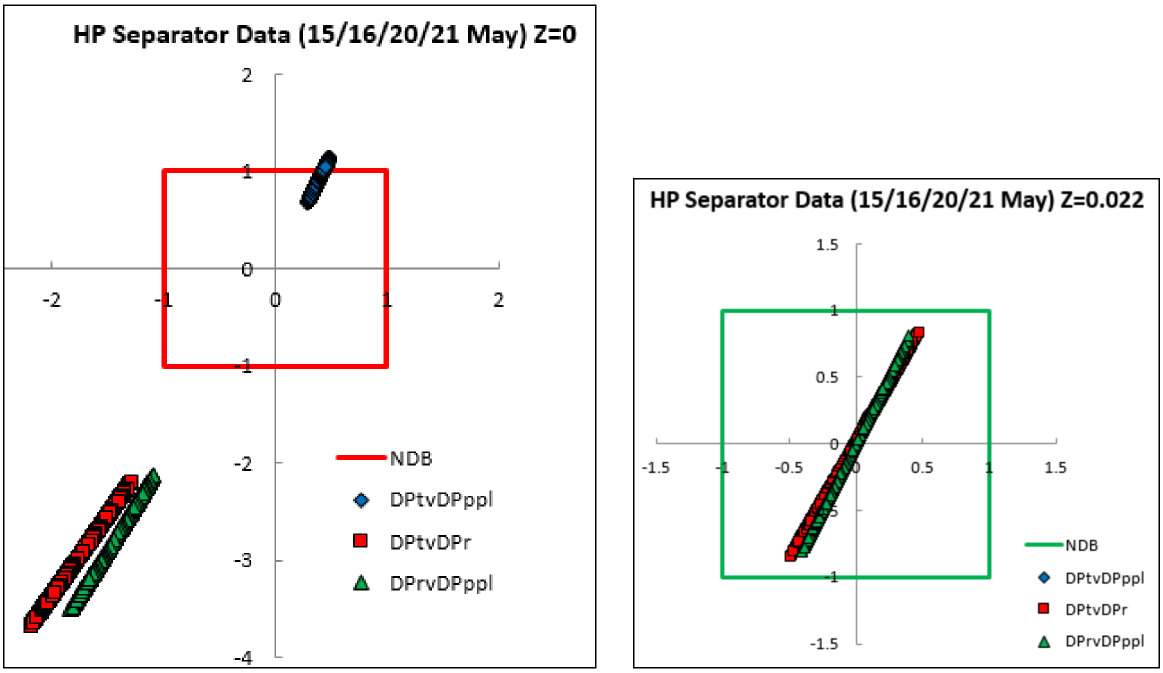
Figure 17 – 12" Orifice test separator meter 'Prognosis' response indicating different liquid loading levels across wells

7.3 24” Orifice High Pressure Separator Meter

Gas and condensate from the seven wells featured in Section 7.2 is comingled and fed into a high pressure separator located on a riser platform. A 24”, 0.4β orifice meter with online verification system is metering the gas outlet of the separator. For the same reasons as described in section 7.2., the ‘recovered DP’ (DPr) is inferred from the measured DPt and the measured DPppl.

The operator knew that the validation system is able to identify wet gas flow and expected the system to confirm that the gas outlet of the test separator was dry gas. This was not the case. After the validation system indicated wet gas flow, modelling confirmed that the fluid contained 6-8% condensate on mass.

The operator applied a published wet gas correction in order to estimate the over-reading on the orifice meter output which required an estimate of the liquid content via sample analysis. The ‘Prognosis’ verification system output can be seen in Figure 18. Left is the ‘non-zeroed’ response indicating wet gas flow. Right is the ‘zeroed’ wet gas response showing no alarms over the periods of 15th, 16th, 20th and 21st May 2017. Now, when sustained alarms are observed, this will (depending on the alarm type) indicate a significant change in liquid loading either in the positive or negative direction, hence the operator will know to analyse a new sample of fluid or to apply a higher uncertainty on the wet gas over-reading estimate.


HP Separator Data (15/16/20/21 May) Z=0

HP Separator Data (15/16/20/21 May) Z=0.022

Figure 18 – Left: 12” orifice, non-zeroed wet gas response. Right: 12” orifice, zeroed wet gas response.

8 EXAMPLE 7: CONOCOPHILLIPS PLUNGER LIFT FIELD TEST

As part of wet gas field trials, Conocophillips installed ‘Prognosis’ on a 4”, 0.7β orifice meter measuring wet gas from an onshore gas well in Texas where a plunger lift system was in operation. The objective was to record and observe the system’s response to varying wet gas through an orifice meter. This orifice meter test was carried out in series with other third party equipment under test. Figure 19 is a photograph and schematic diagram of the orifice meter with ‘Prognosis’.

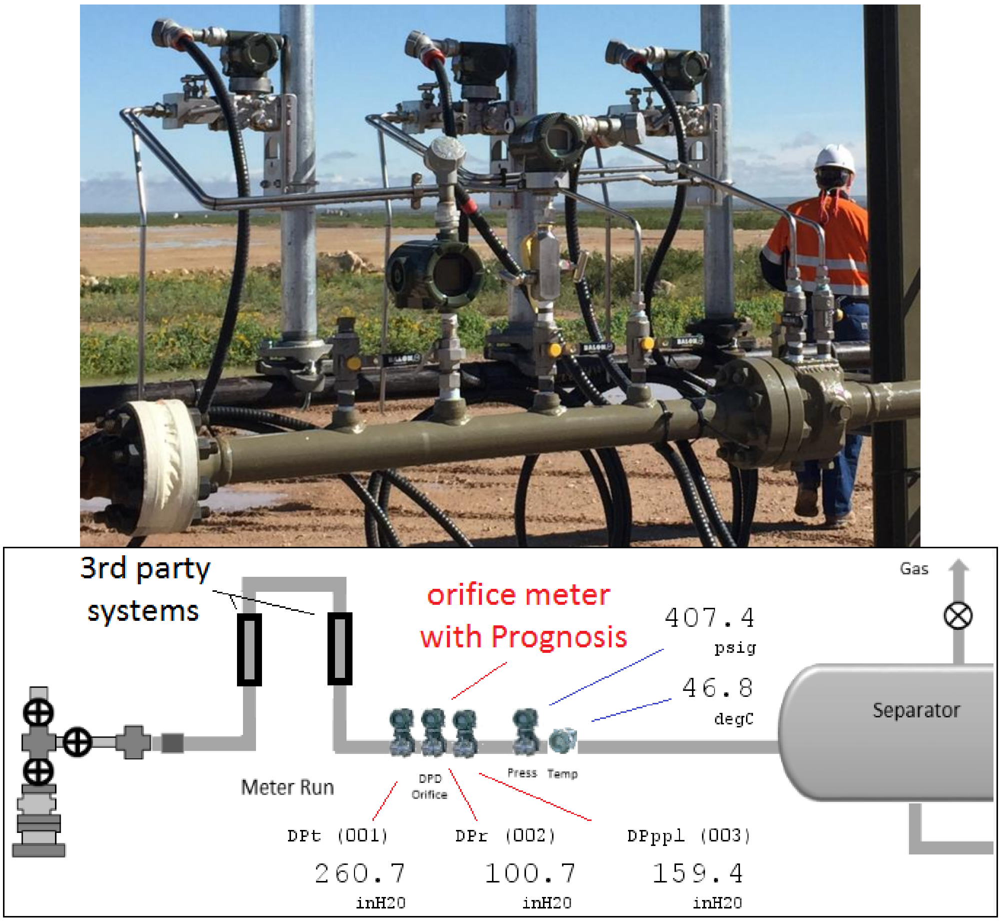
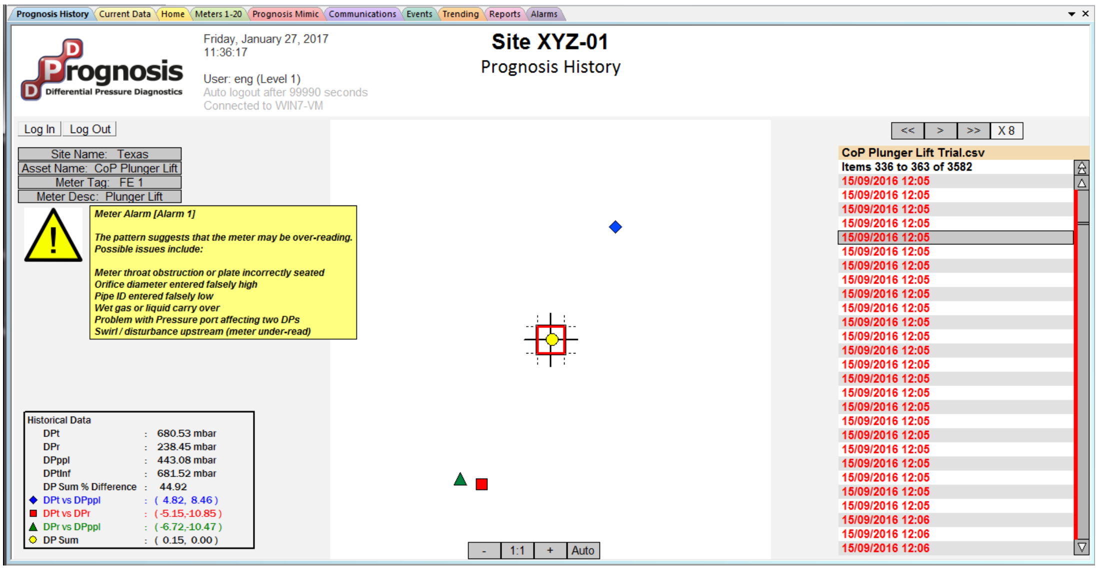


Figure 19 – Photograph and schematic diagram of orifice meter with 'Prognosis' at the wellhead

Figure 20 shows a snapshot of historical data when the liquid loading was at its highest value. Figure 21 shows a snapshot of historical data when the liquid loading had reduced. These results are as expected. The general plot is indicative of wet gas flow. As the liquid loading reduces the diagnostic points move closer to the origin, i.e. closer to the dry gas performance. The system shows an alarm and one of the displayed causes of that alarm is 'wet gas or liquid carry-over'.



Friday, January 27, 2017
11:36:17

User: eng (Level 1)
Auto logout after 99990 seconds
Connected to WIN7-VM

Site XYZ-01
Prognosis History

Site Name: Texas
Asset Name: CoP Plunger Lift
Meter Tag: FE 1
Meter Desc: Plunger Lift

Meter Alarm [Alarm 1]

The pattern suggests that the meter may be over-reading.
Possible issues include:

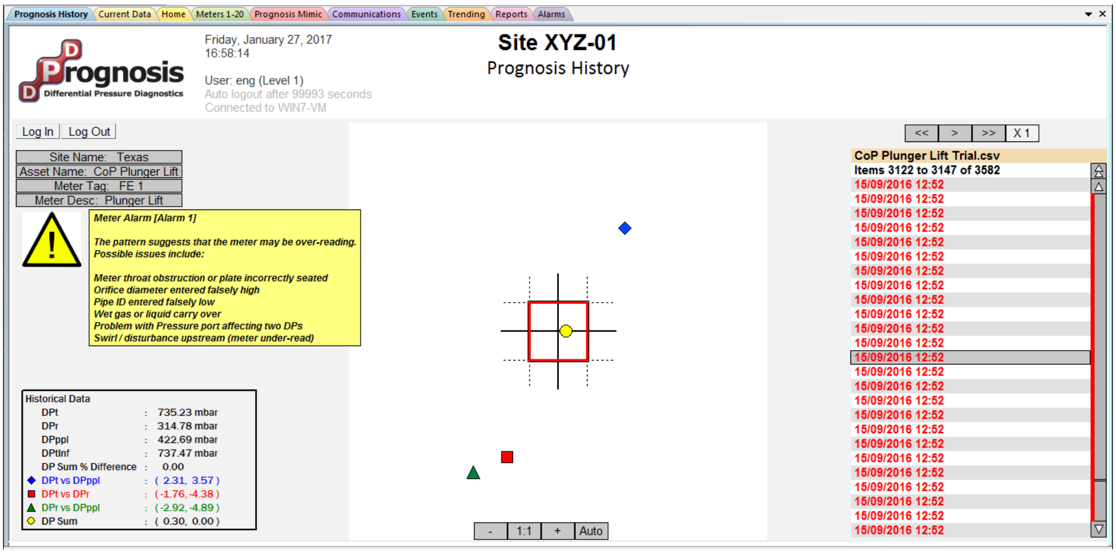
Meter throat obstruction or plate incorrectly seated
Orifice diameter entered falsely high
Pipe ID entered falsely low
Wet gas or liquid carry over
Problem with Pressure port affecting two DPs
Swirl / disturbance upstream (meter under-read)

Historical Data

DPt	:	680.53 mbar
DPr	:	238.45 mbar
DPppl	:	443.08 mbar
DPtInf	:	681.52 mbar
DP Sum % Difference	:	44.92
◆ DPt vs DPppl	:	(4.82, 8.46)
■ DPt vs DPr	:	(-5.15,-10.85)
▲ DPr vs DPppl	:	(-6.72,-10.47)
○ DP Sum	:	(0.15, 0.00)

CoP Plunger Lift Trial.csv
Items 336 to 363 of 3582
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:05
15/09/2016 12:06
15/09/2016 12:06
15/09/2016 12:06

Figure 20 – Response to wet gas flow, high liquid loading



Friday, January 27, 2017
16:58:14

User: eng (Level 1)
Auto logout after 99993 seconds
Connected to WIN7-VM

Site XYZ-01
Prognosis History

Site Name: Texas
Asset Name: CoP Plunger Lift
Meter Tag: FE 1
Meter Desc: Plunger Lift

Meter Alarm [Alarm 1]

The pattern suggests that the meter may be over-reading.
Possible issues include:

Meter throat obstruction or plate incorrectly seated
Orifice diameter entered falsely high
Pipe ID entered falsely low
Wet gas or liquid carry over
Problem with Pressure port affecting two DPs
Swirl / disturbance upstream (meter under-read)

Historical Data

DPt	:	735.23 mbar
DPr	:	314.78 mbar
DPppl	:	422.69 mbar
DPtInf	:	737.47 mbar
DP Sum % Difference	:	0.00
◆ DPt vs DPppl	:	(2.31, 3.57)
■ DPt vs DPr	:	(-1.76, -4.38)
▲ DPr vs DPppl	:	(-2.92, -4.89)
○ DP Sum	:	(0.30, 0.00)

CoP Plunger Lift Trial.csv
Items 3122 to 3147 of 3582
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
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15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52
15/09/2016 12:52

Figure 21 – Response to wet gas flow, low liquid loading

Figure 22 presents all data collected during one plunger cycle. The sensitivity settings in use are the 'default' settings. Figure 22 shows that the 'recovered to permanent pressure loss ratio' (DPr/DPppl) is the most sentitive of all the diagnostics to changes in wet gas liquid loading through an orifice meter.

This is another example of the DP meter verification system being deliberately used to trend a known issue.

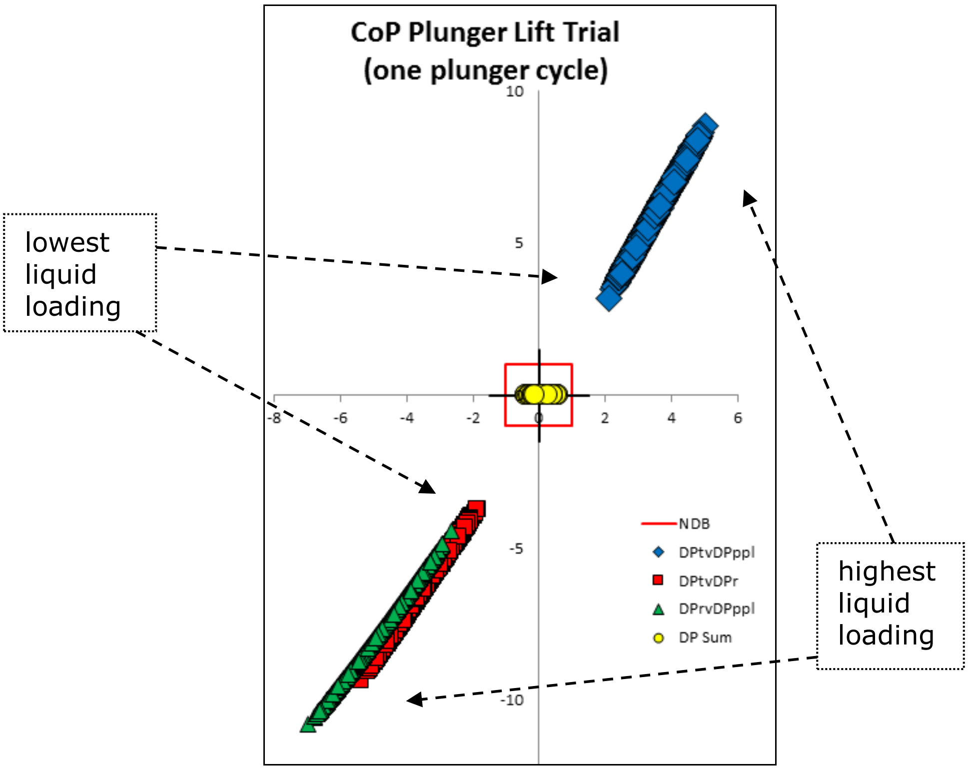
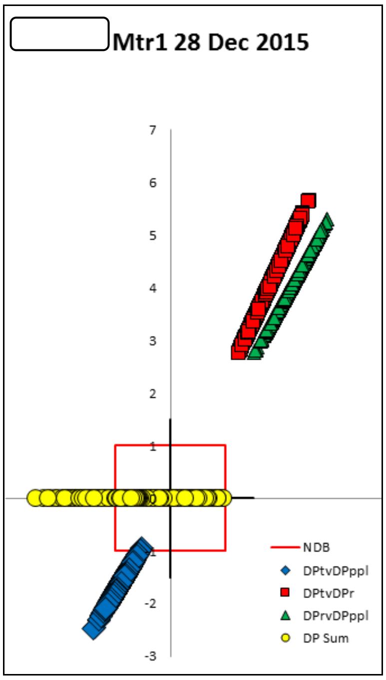


Figure 22 – Multi-data plot using 'default' sensitivity settings

9 EXAMPLE 8: 3 x 4” ORIFICE, OFFSHORE WEST OF SHETLAND

The DP meter validation system was installed offshore to monitor three 4”, 0.51β orifice meters. Following initial start up, the operator was aware of process issues causing liquid contaminates to be present; this issue was in turn causing blockages in the DP Transmitter impulse lines. The Technician on site reported the effectiveness of the ‘Prognosis’ system which he observed to be in alarm prior to clearing the transmitter impulse lines, after which all alarms cleared.

Figure 23 (left) shows multiple data from a 24 hour period where impulse line blockages were present. Figure 24 (right) shows multiple data from a 24 hour period one month later, when no impulse line blockages were present. As periodic unstable process conditions are evident in Figure 24 (like many production flows the flow periodically fluctuating causes transient short lived alarms) the operator may wish to reduce sensitivity settings in order to see no alarms during these periods. However, as the validation system screen is observed frequently on site rather than alarms being monitored periodically remotely, the operator preference is to keep the ‘default’ sensitivity settings in order that the system may be as responsive as possible to sustained problems re-occuring. This system then provides the operator with real-time and helpful information on the performance of the meter system.



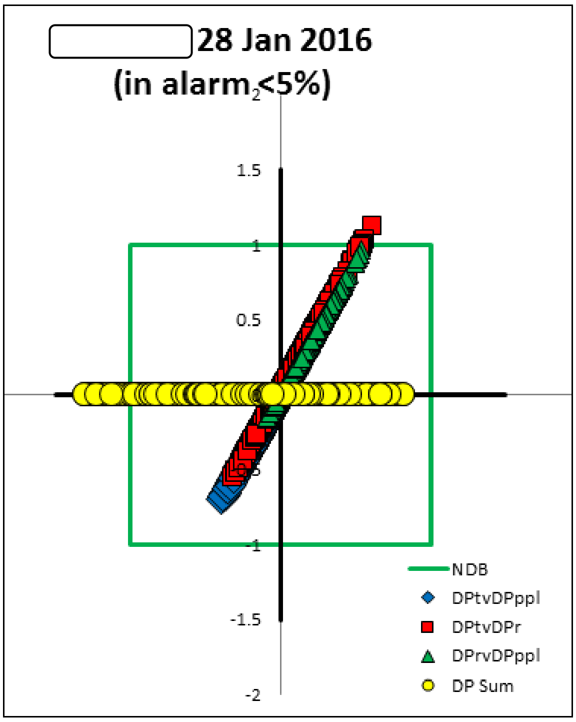


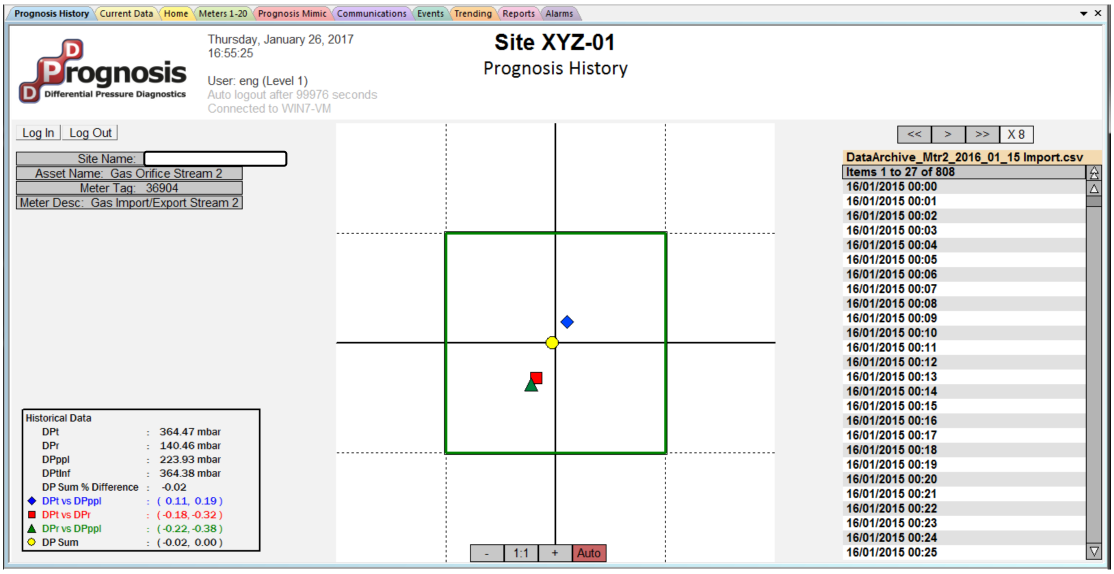
Figure 23 (Left) - Multi-data plot showing response during a problem period

Figure 24 (Right) - Multi-data plot showing alarms cleared

As the site Technicians are able to observe the validation system response in real time on a dedicated monitor in the control room, they are able to identify when it may be necessary to perform corrective action (e.g., blowing down impulse lines) and when no action is required. This is an example of condition-based maintenance (CBM) in action.

10 EXAMPLE 9: 2 x 3” ORIFICE IMPORT/EXPORT METERS, NORTH SEA

Two 0.6β orifice meters, located offshore in the North Sea are used for both ‘Import’ and ‘Export’ flow. Figure 25 shows the typical verifcation system response from one of the meters observed both offshore and via remote access onshore. ‘Default’ sensitivity settings are used.



Thursday, January 26, 2017
16:55:25

User: eng (Level 1)
Auto logout after 99976 seconds
Connected to WIN7-VM

Site XYZ-01
Prognosis History

Site Name:
Asset Name: Gas Orifice Stream 2
Meter Tag: 36904
Meter Desc: Gas Import/Export Stream 2

```
Historical Data
     DPt                   :  364.47 mbar
     DPr                   :  140.46 mbar
     DPppl                 :  223.93 mbar
     DPtInf                :  364.38 mbar
     DP Sum % Difference   :   -0.02
  ◆  DPt vs DPppl          :  (  0.11,  0.19 )
  ■  DPt vs DPr            :  ( -0.18, -0.32 )
  ▲  DPr vs DPppl          :  ( -0.22, -0.38 )
  ○  DP Sum                :  ( -0.02,  0.00 )
```

```
DataArchive_Mtr2_2016_01_15 Import.csv
Items 1 to 27 of 808
16/01/2015 00:00
16/01/2015 00:01
16/01/2015 00:02
16/01/2015 00:03
16/01/2015 00:04
16/01/2015 00:05
16/01/2015 00:06
16/01/2015 00:07
16/01/2015 00:08
16/01/2015 00:09
16/01/2015 00:10
16/01/2015 00:11
16/01/2015 00:12
16/01/2015 00:13
16/01/2015 00:14
16/01/2015 00:15
16/01/2015 00:16
16/01/2015 00:17
16/01/2015 00:18
16/01/2015 00:19
16/01/2015 00:20
16/01/2015 00:21
16/01/2015 00:22
16/01/2015 00:23
16/01/2015 00:24
16/01/2015 00:25
```

Figure 25 – Example ‘Prognosis’ system response during Import flow

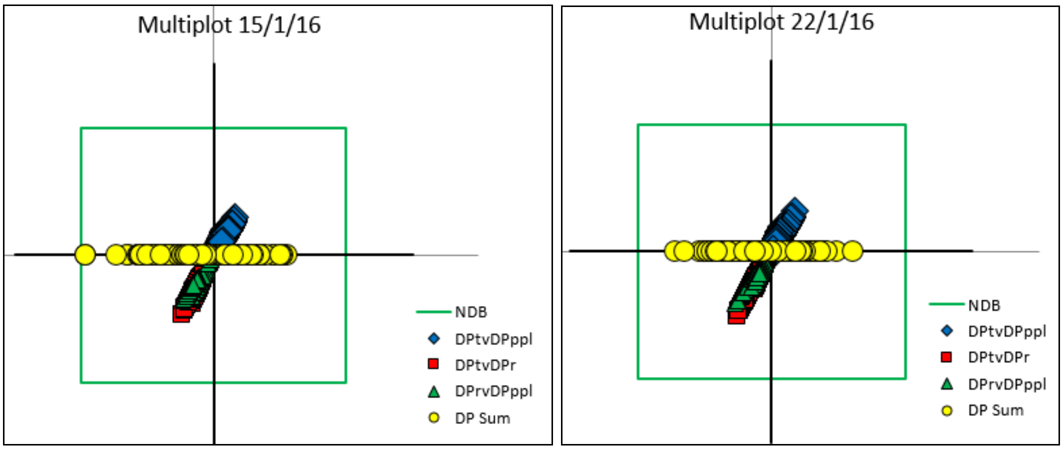


Figure 26 – Multiple data plots from 1 week apart

Figure 26 shows two sets of multiple data sets recorded one week apart. The results are very repeatable and indicate good meter performance.

For Orifce meters with beta ratio less than 0.55, the prediction of the PLR is that which can be found in ISO 5167-2 2003 [9], section 5.4.1. In this real example, as the beta ratio is larger than 0.55, the prediction of the PLR automatically changes to that published by CEESI in [6] which is based on multiple industry data sets from orifice meters with the third tapping point at 6D downstream. An alternative PLR prediction is offered by Reader-Harris in [7].

The comparisons in Figure 27 indicate that whilst the NEL published PLR prediction is higher than the ISO and CEESI publised predictions, all published PLR equations predict the actual found pressure field within a low uncertainty. In this case CEESI and NEL equations both predict this actual field data to within +/-1%.

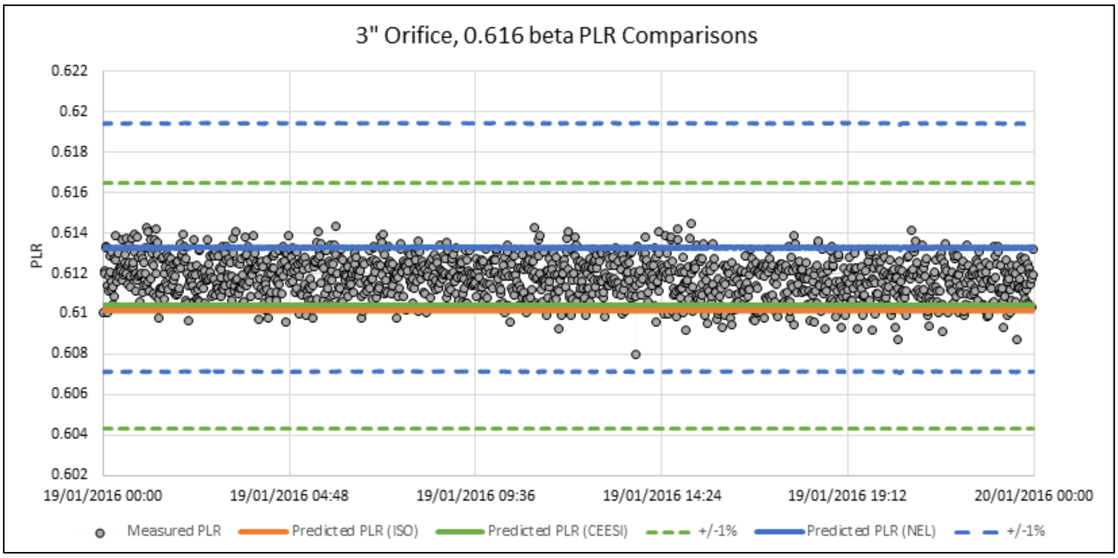
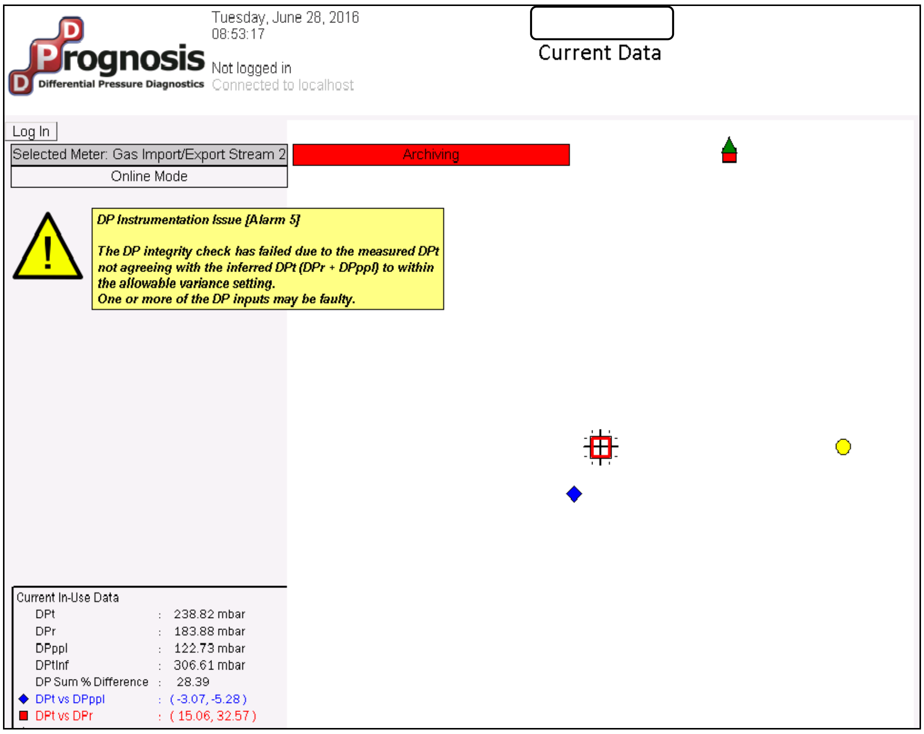


Figure 27 – Measured PLR vs. ISO, CEESI and NEL published predictions

A problem occurred with these meters in mid-2016. Following start up after a process shutdown the onshore metering support team observed a ‘DP Integrity’ alarm. The conclusion from this response was that more than one of the DP inputs received by ‘Prognosis’ was incorrect and this may be causing a significant bias in reported flow rate. Figure 28 shows the observed response from the operator’s screen on site.



Tuesday, June 28, 2016
08:53:17
Not logged in
Connected to localhost

Selected Meter: Gas Import/Export Stream 2
Online Mode

DP Instrumentation Issue [Alarm 5]

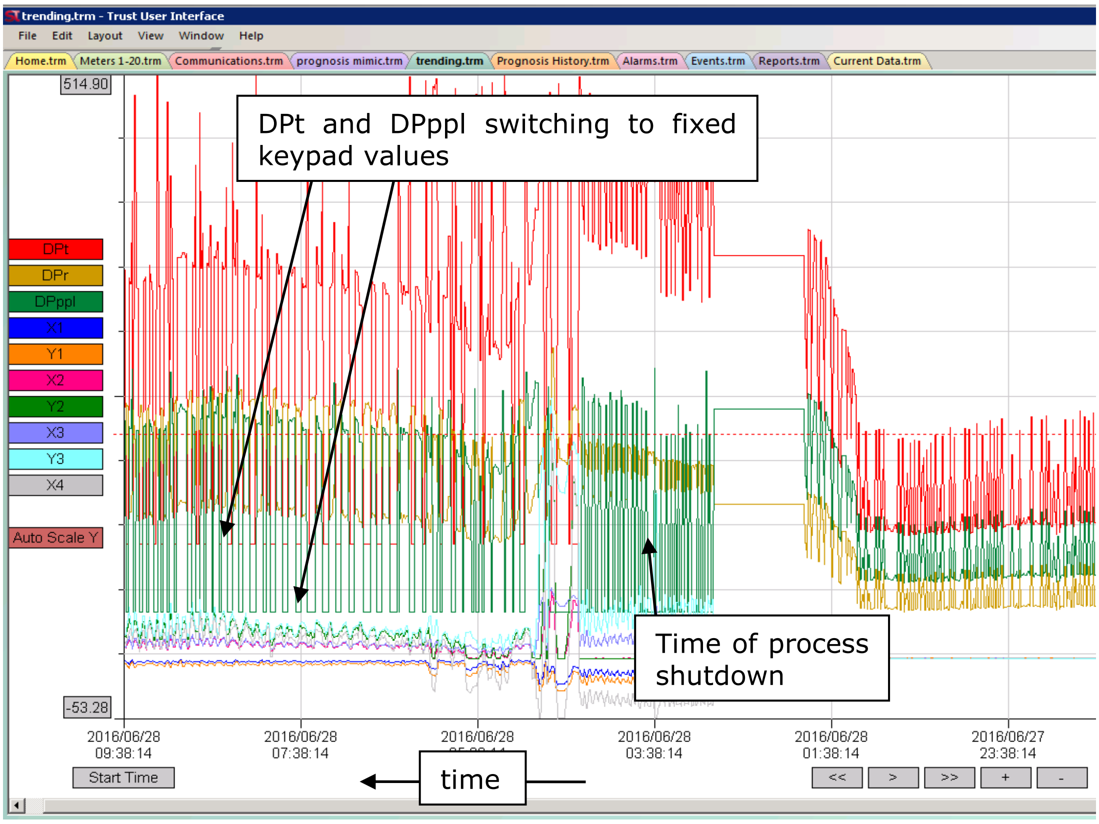
The DP integrity check has failed due to the measured DPt not agreeing with the inferred DPt (DPr + DPppl) to within the allowable variance setting.
One or more of the DP inputs may be faulty.

Current In-Use Data
DPt : 238.82 mbar
DPr : 183.88 mbar
DPppl : 122.73 mbar
DPtInf : 306.61 mbar
DP Sum % Difference : 28.39
◆ DPt vs DPppl : (-3.07, -5.28)
■ DPt vs DPr : (15.06, 32.57)

Figure 28 – DP Integrity Alarm observed

The system's trending display showed the problem was communal to both the 'traditional' (DPt) and 'Permanent Pressure Loss' (DPppl) DP. These DP readings were found to be repeatedly switching from a measured value to a fixed value of 100mbar and 40mbar respectively (see Figure 29).

The measured values immediately prior to switching to a fixed value were consistently at the upper range limit of the respective DP transmitters, i.e. these DP transmitters were being periodically over-ranged (or 'saturated') due to flow surges following the process shutdown. During saturation, default incorrect keypad values in the flow computer were being automatically used.



DPt and DPppl switching to fixed keypad values

Time of process shutdown

time

Figure 29 – Trending display revealed the cause of the alarms

The surge flows were causing a significant mis-measurement. However, 'Prognosis' detected this issue promptly, and the operator was able to quicky adjust process conditions in order to reduce the flow through this meter system, thereby avoiding further mis-measurements. In addition, as the verification system identified the exact time when the issue began it was possible to calculate and correct for the approximate mis-measurement thereby avoiding challenges by pipeline partners. Without the verification system the operator would have been unaware of the problem and associated measurement errors.

11 SUMMARY AND CONCLUSIONS

Several examples of operator field data have been shown including many normal cases where the 'Prognosis' DP Meter validation system provides valuable assurance on a daily basis of good meter system performance. This is the most common verification system result, i.e. it verifies the meter is serviceable and reduces the operator's maintenance workload. The system allows the operator to adopt a condition-based maintenance strategy when it comes to meter inspections and DP Transmitter maintenance checks and calibrations.

In circumstances where a specific issue is suspected (e.g., wet gas flow), the validation system is able to confirm whether or not the meter does indeed have a problem or not. Only when a problem is registered does the operator then have to intervene, or then use the validation tool as a trending tool until a permanent solution can be applied.

In cases where no adverse flow conditions are identified or suspected the operator uses standard baseline and sensitivity settings as default. After experience is gained operating ‘Prognosis’ on a specfic meter, and there is confidence in that meter’s serviceability, the operator may choose to increase the sensitivity of the verifcation tool in order to see smaller problems as they arise in the future.

Where a specific issue is observed to be intermittent, the operator can use the validation system to be alerted to that specific issue as it arises. The operator then knows when remedial action needs to be taken and/or exactly when and for how long a significant mis-measurement occurs.

Where a specific ongoing issue is known and is being dealt with (e.g., wet gas is being corrected for), the operator may adjust the ‘Prognosis’ baseline and sensitivity settings in order to monitor the issue with ease and gain confidence in the corrective action or understand when the corrective action needs adjusting.

Operators without a comprehensive verification system are effectively operating ‘blind’. Operators of DP meters who use these self-diagnostic / verification capabilities cease to operate ‘blind’ and benefit from real time ongoing validation, being alerted to potentially costly issues as they occur, and profiting from all the advantages of condition based maintenance.

Unfortunately, many operators incorrectly assume that they cannot adopt the use of on line diagnostics as it will increase overall maintenance costs. Many contracts have legacy clauses based on the time when there were no diagnostic systems and therefore regular scheduled maintenance was necessary. Although technology has moved on, some contracts have not, and still imply *because there are no diagnotsics* it is necessary that all DP transmitters must be regulary recalibrated. This is to the detrement of modern best practice, and industry, and operators would greatly benefit from these contracts being modernized to reflect modern technical capabilities.

In reality the widespread use of on line diagnostics as part of operator validation procedures will reduce the need for scheduled maintenance checks, increase operational efficiency and avoid costly mis-measurement disputes.

12 APPENDIX

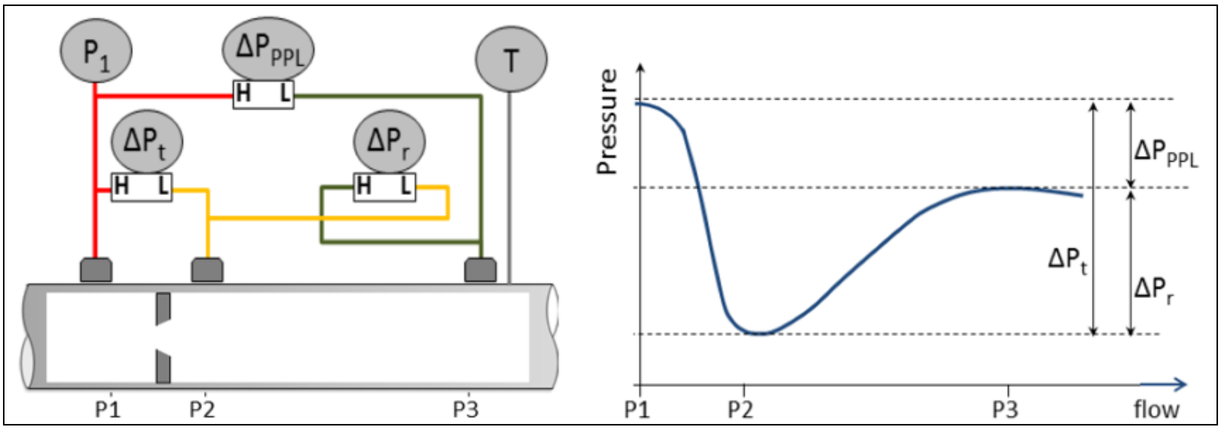


Figure 30 - Orifice meter with instrumentation sketch and pressure field graph

Figure 30 shows a sketch of a generic DP meter with three DP readings and a simplified pressure field created by the meter. The DP meter has a third pressure tap downstream of the two traditional pressure ports. This allows three DPs to be read, i.e. the traditional (ΔP_t), recovered (ΔP_r) and permanent pressure loss (ΔP_{PPL}) DPs. These DPs are related by equation 1. The percentage difference between the inferred traditional DP (i.e. the sum of the recovered & PPL DPs) and the read DP is δ%, while the maximum allowed difference is θ%.

DP Summation: $\Delta P_t = \Delta P_r + \Delta P_{PPL}$, uncertainty $\pm\ \theta\%$ --- (1)

Traditional flow calculation: $\dot{m}_{trad} = f_t(\Delta P_t)$, uncertainty ± x% --- (2)

Expansion flow calculation: $\dot{m}_{\exp} = f_r(\Delta P_r)$, uncertainty ± y% --- (3)

PPL flow calculation: $\dot{m}_{PPL} = f_{PPL}(\Delta P_{PPL})$, uncertainty ± z% --- (4)

Each DP can be used to meter the flow rate, as shown in equations 2, 3 & 4. Here $\dot{m}_{trad}$, $\dot{m}_{\exp}$ & $\dot{m}_{PPL}$ are the mass flow rate predictions of the traditional, expansion & PPL flow rate calculations. **Every DP meter is three flow meters in one body**. Symbols f_t, f_r & f_{PPL} represent the traditional, expansion & PPL flow rate calculations respectively, and, $x\%, y\% \,\&\, z\%$ represent the uncertainties of each of these flow rate predictions respectively. Inter-comparison of these flow rate predictions produces three diagnostic checks. The percentage difference of the PPL to traditional flow rate calculations is denoted as $\psi\%$. The allowable difference is the root sum square of the PPL & traditional meter uncertainties, $\phi\%$. The percentage difference of the expansion to traditional flow rate calculations is denoted as $\lambda\%$. The allowable difference is the root sum square of the expansion & traditional meter uncertainties, $\xi\%$. The percentage difference of the expansion to PPL flow rate calculations is denoted as $\chi\%$. The allowable difference is the root mean square of the expansion & PPL meter uncertainties, $\nu\%$.

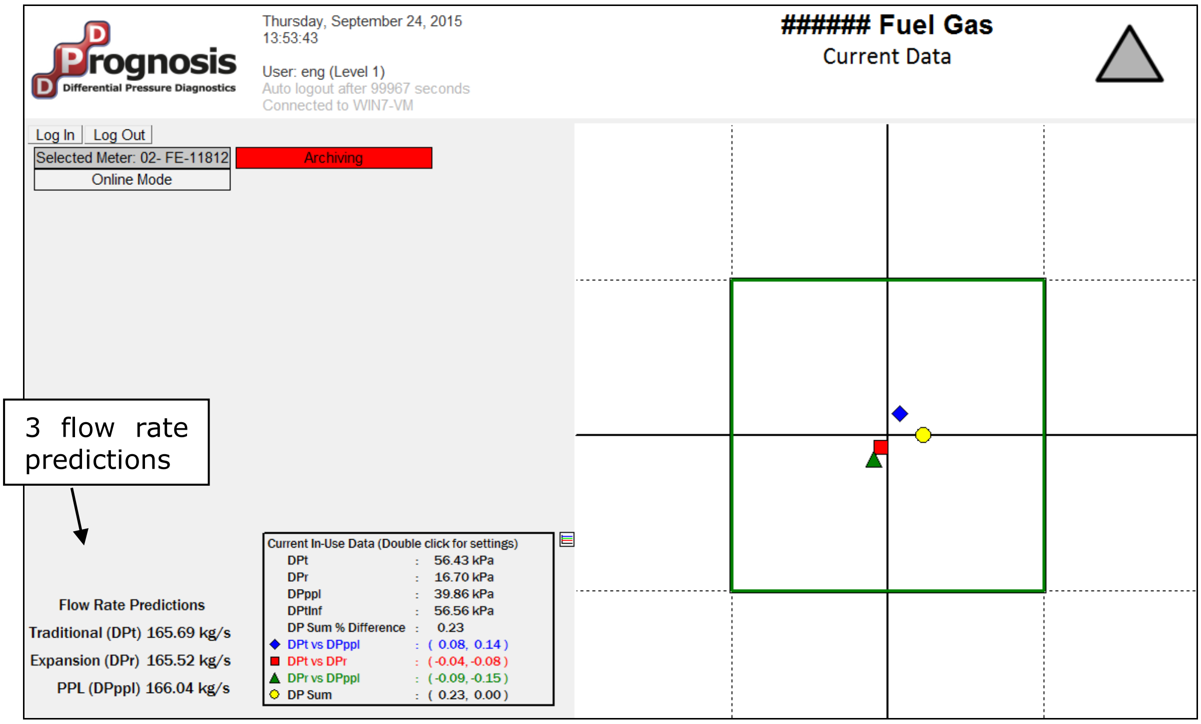
Reading these three DPs produces three DP ratios, the 'PLR' (i.e. the PPL to traditional DP ratio), the PRR (i.e. the recovered to traditional DP ratio), the RPR (i.e. the recovered to PPL DP ratio). DP meters have predictable DP ratios. Therefore, comparison of each read to expected DP ratio produces three diagnostic checks. The percentage difference of the read to expected PLR is denoted as $\alpha\%$.

The allowable difference is the expected PLR uncertainty, $a\%$. The percentage difference of the read to expected PRR is denoted as $\gamma\%$. The allowable difference is the expected RPR uncertainty, $b\%$. The percentage difference of the read to expected RPR is denoted as $\eta\%$. The allowable difference is the expected RPR uncertainty, $c\%$. These seven diagnostic results can be shown on the operator interface as plots on a graph (see Figure 31). That is, we can plot the following four co-ordinates to represent the seven diagnostic checks:

$$\left(\psi\%/\phi\%, \alpha\%/a\%\right), \left(\lambda\%/\xi\%, \gamma\%/b\%\right), \left(\chi\%/\nu\%, \eta\%/c\%\right) \ \& \ \left(\delta\%/\theta\%, 0\right).$$

For simplicity we can refer to these points as (x_1,y_1), (x_2,y_2), (x_3,y_3) & (x_4,0).

Dividing the seven raw diagnostic outputs by their respective uncertainties is called 'normalisation'. A Normalised Diagnostics Box (or 'NDB') of corner coordinates (1, 1), (1,-1), (-1,-1) & (-1, 1) can be plotted on the same graph (see Figure 31). This is the standard user interface with the diagnostic system 'Prognosis'. All four diagnostic points inside the NDB indicate a serviceable DP meter. Any point outside of the NDB indicates a possible meter system malfunction and potential measurement bias.



Thursday, September 24, 2015
13:53:43

User: eng (Level 1)
Auto logout after 99967 seconds
Connected to WIN7-VM

Selected Meter: 02- FE-11812
Online Mode

Flow Rate Predictions
Traditional (DPt) 165.69 kg/s
Expansion (DPr) 165.52 kg/s
PPL (DPppl) 166.04 kg/s

Current In-Use Data (Double click for settings)

	DPt	:	56.43 kPa
	DPr	:	16.70 kPa
	DPppl	:	39.86 kPa
	DPtInf	:	56.56 kPa
	DP Sum % Difference	:	0.23
◆	DPt vs DPppl	:	(0.08, 0.14)
■	DPt vs DPr	:	(-0.04, -0.08)
▲	DPr vs DPppl	:	(-0.09, -0.15)
○	DP Sum	:	(0.23, 0.00)

Figure 31 - Display showing NDB and diagnostic results (good meter performance)

By analysing the diagnostic response continually and in real time (with no operator intervention required), the 'Prognosis' software will automatically provide a system alarm when any point is outside of the NDB for longer than a configurable 'alarm delay' period and also a 'shortlist' of possible issues which are known to cause the observed response (discounting other problems that do not cause such a response). In some cases (e.g., DP instrumentation issue), the software is able to tell the end user specifically what issue exists. In the case of an issue with the 'traditional' meter DP reading the diagnostic system's flow rate prediction over-determination provides **two alternative flow rate predictions**.

13 REFERENCES

[1] Cousins, T., Steven, R. "Setting the STANDARD – Integrating Meter Diagnostics Into Flow Metering Standards", North Sea Flow Measurement Workshop, October 2015, Norway.

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