RESULTS OF TESTING AN ORIFICE METER DIAGNOSTIC SYSTEM AT A MEXICAN GOVERNMENT WATER FLOW FACILITY

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Abstract

In August 2012 CIATEQ tested a new DP meter diagnostic system (called "Prognosis") on 4", 0.5 beta ratio, flange tapped orifice meters. These comprehensive tests, at the CIATEQ water flow laboratory at Aguascalientes, Mexico, were the first third party organized liquid flow tests of this technology. CIATEQ considers this DP meter diagnostic system potentially compliant with new Mexican government flow metering regulations. Official authorities were present to witness these tests. In this paper the latest developments of the working principles of the diagnostic system are described. The operators interface with the diagnostics is also described.

Introduction

A 4" inch, 0.50 beta ratio orifice meter was tested at the CIATEQ water flow facility in Mexico in 2012. The orifice meter was fully compliant with ISO 5167 Part 2 [1]. The aim of these tests was to independently show the DP Diagnostics developed diagnostic system for generic DP meters in operation.

Background

In 2008 and 2009 a generic DP meter self diagnostic methodology [2,3] was proposed to industry by DP Diagnostics. A diagnostics screen displaying the real time diagnostic results was proposed. These DP meter diagnostic principles are fully applicable to the orifice meter. This patented DP meter diagnostic system is created by DP Diagnostics LLC ("DPD") and offered to the hydrocarbon production industry in the form of the software package "Prognosis" by Swinton Technology Ltd.

As an initial test series in June 2012 CIATEQ carried out independent tests where the required standard meter and diagnostic data was logged by CIATEQ without the Prognosis system attached. This raw data was then analysed by spreadsheet to prove that the DPD diagnostic system worked as described. In August 2012 DP Diagnostics attended the CIATEQ water flow facility and installed a computer with Prognosis for direct orifice meter tests.

These combined CIATEQ orifice meter test series matched similar successful tests carried out in the field by BP and ConocoPhillips in the UK [5] and laboratory tests carried out by ATMOS. The results were as predicted. The correctly operating orifice meter behaved as ISO 5167 part 2 predicts.

When a meter malfunction was induced by the laboratory the diagnostics method / Prognosis indicated a meter malfunction, stated whether the malfunction source is DP transmitter or meter body based, and then gave a list of possible malfunctions (while confirming what malfunctions can be ruled out).

Problem Definition and Theory Exposition

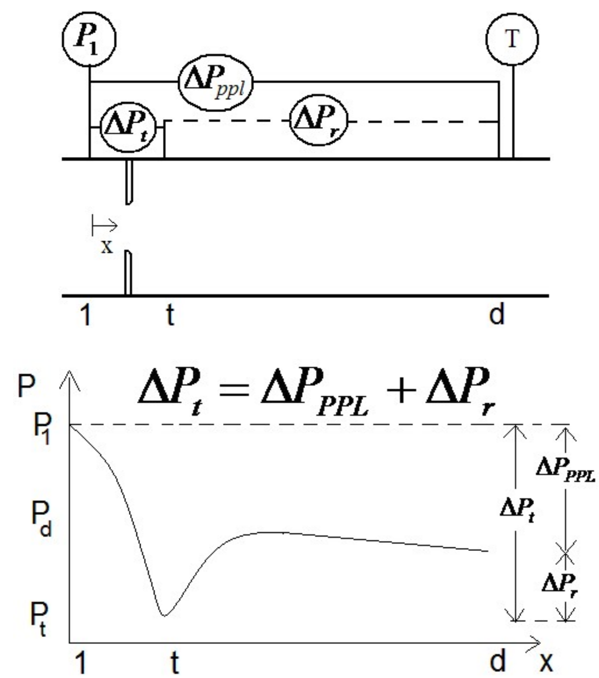

Fig 1. Orifice meter with instrumentation sketch and pressure fluctuation graph.

Figure 1 shows an orifice meter with instrumentation sketch and the (simplified) pressure fluctuation through the meter body. Traditional orifice meters read the inlet pressure (P_1), the downstream temperature (T, not shown) and the differential pressure (ΔP_t) between the inlet pressure tap (1) and a pressure tap positioned at the low pressure immediately downstream of the plate (t). Note that the orifice meter in Figure 1 has a third pressure tap (d) further downstream from the plate. This addition to the traditional meter design allows the measurement of two extra DPs. That is, the differential pressure between the downstream (d) and the low (t) pressure taps (or "recovered" DP, ΔP_r) and the differential pressure between the inlet (1) and the downstream (d) pressure taps (i.e. the permanent pressure loss, ΔP_{PPL}, sometimes called the "PPL" or "total head loss").

The sum of the recovered DP and the PPL equals the traditional differential pressure (equation 1).

$$\Delta P_t = \Delta P_r + \Delta P_{PPL} \quad \text{--- (1)}$$

Traditional Equation: $$\dot{m}_t = EA_t \varepsilon C_d \sqrt{2\rho \Delta P_t} \quad \text{-- (2)}$$
uncertainty ± x%

Expansion Equation: $$\dot{m}_r = EA_t K_r \sqrt{2\rho \Delta P_r} \quad \text{-- (3)}$$
uncertainty ± y%

PPL Equation: $$\dot{m}_{ppl} = AK_{PPL} \sqrt{2\rho \Delta P_{PPL}} \quad \text{-- (4)}$$
uncertainty ±z%

The traditional orifice meter flow rate equation is shown here as equation 2. Traditionally, this is the only flow rate calculation. However, with the additional downstream pressure tap three flow equations can be produced. That is, the recovered DP can be used to find the flow rate with an "expansion" flow equation (see equation 3) and the PPL can be used to find the flow rate with a "PPL" flow equation (see equation 4). Note $\dot{m}_t$, $\dot{m}_r$ and $\dot{m}_{PPL}$ represents the traditional, expansion and PPL mass flow rate equation predictions of the actual mass flow rate ($\dot{m}$) respectively. The symbol ρ represents the inlet fluid density. Symbols E , A and A_t represent the velocity of approach, the inlet cross sectional area and the minimum (or "throat") cross sectional area through the meter respectively. These three values are constants for a set meter geometry. The parameter ε is an expansion factor accounting for gas density fluctuation through the meter. (For liquids ε =1.) The terms C_d, K_r and K_{PPL} represent the discharge coefficient, the expansion coefficient and the PPL coefficient respectively. These parameters are usually expressed as functions of the orifice meter geometry and the flows Reynolds number.

$$\mathrm{Re} = 4\dot{m} / \pi \mu D \quad \text{--- (5)}$$

The Reynolds number is expressed as equation 5. Note that μ is the fluid viscosity and D is the inlet diameter. In this case, as the Reynolds number (Re) is flow rate dependent, these flow rate predictions must be obtained by iterative methods within the flow computer. A detailed derivation of these three flow rate equations is given by Steven [2].

Solution and Analysis Procedure

Every orifice meter run is in effect three flow meters. As there are three flow rate equations predicting the same flow through the same meter body there is the potential to compare the flow rate predictions and hence have a diagnostic system. Naturally, all three flow rate equations have individual uncertainty ratings (say x%, y% & z% as shown in equations 2 through 4). Therefore, even if a DP meter is operating correctly, no two flow predictions would match *precisely*. However, a correctly operating meter should have no difference between any two flow equations greater than the sum of the two uncertainties (and typically no greater than the rms of the two uncertainties). The system therefore has three more uncertainties, i.e. the maximum allowable difference between any two flow rate equations, as shown in equation set 6a to 6c. This allows a self diagnosing system. If the percentage difference between any two flow rate equations is less than that equation pair's rms of uncertainties, then no potential problem is found and the traditional flow rate prediction can be trusted. If however, the percentage difference between any two flow rate equations is greater than that equation pair's rms of uncertainties then this indicates a metering problem and the flow rate predictions should not be trusted. The three flow rate percentage differences are calculated by equations 7a to 7c.

Traditional & PPL Meters allowable difference ($\phi\%$):

$$\phi\,\% = \sqrt{(x\%)^2 + (z\%)^2} \quad \text{-- (6a)}$$

Traditional & Expansion Meters allowable difference ($\xi\%$):

$$\xi\% = \sqrt{(x\%)^2 + (y\%)^2} \quad \text{-- (6b)}$$

Expansion & PPL Meters allowable difference ($\upsilon\%$):

$$\upsilon\% = \sqrt{(y\%)^2 + (z\%)^2} \quad \text{-- (6c)}$$

Traditional to PPL Meter Comparison:

$$\psi\,\% = \left\{ \left(\dot{m}_{PPL} - \dot{m}_t \right) \Big/ \dot{m}_t \right\} * 100\% \quad \text{-- (7a)}$$

Traditional to Expansion Meter Comparison:

$$\lambda\,\% = \left\{ \left(\dot{m}_r - \dot{m}_t \right) \Big/ \dot{m}_t \right\} * 100\% \quad \text{-- (7b)}$$

PPL to Expansion Meter Comparison:

$$\chi\,\% = \left\{ \left(\dot{m}_r - \dot{m}_{PPL} \right) \Big/ \dot{m}_{PPL} \right\} * 100\% \quad \text{-- (7c)}$$

This diagnostic methodology uses the three individual DP's to independently predict the flow rate and then compares these results. In effect, the individual DP's are therefore being directly compared. However, it is possible to take a different diagnostic approach. The **P**ressure **L**oss **R**atio (or "PLR") is the ratio of the PPL to the traditional DP. <u>The PLR is almost constant for orifice meters operating with single phase homogenous flow</u>, as indicated by ISO 5167 [3]. We can rewrite Equation 1:

$$\frac{\Delta P_r}{\Delta P_t} + \frac{\Delta P_{PPL}}{\Delta P_t} = 1 \text{ -- (1a)} \quad \text{where } \frac{\Delta P_{PPL}}{\Delta P_t} \text{ is the PLR.}$$

From equation 1a, if the PLR is a constant set value then both the **P**ressure **R**ecovery **R**atio or "PRR", (i.e. the ratio of the recovered DP to traditional DP) and the **R**ecovered DP to **P**PL **R**atio, or "RPR" must then also be constant set values. That is, all three DP ratios available from the three DP's read are effectively constant values for any correctly operating orifice meter. Thus we have:

PPL to Traditional DP ratio (PLR):

$\left(\Delta P_{PPL} / \Delta P_t\right)_{set}$, uncertainty ± a%

Recovered to Traditional DP ratio (PRR):

$\left(\Delta P_r / \Delta P_t\right)_{set}$, uncertainty ± b%

Recovered to PPL DP ratio (RPR):

$\left(\Delta P_r / \Delta P_{PPL}\right)_{set}$, uncertainty ± c%

Here then is another method of using the three DP's to check an orifice meters health. Actual DP ratios found in service can be compared to set known correct operational values. Let us denote the difference between this read (PLR_{read}) and correct (PLR_{set}) operation PLR value as α, the difference between the read (PRR_{read}) and correct (PRR_{set}) operation PRR value as γ, and the difference between the read (RPR_{read}) and the correct (RPR_{set}) operation RPR as η. These values are found by equations 8a to 8c.

$$\alpha\% = \left\{\left[PLR_{read} - PLR_{set}\right] / PLR_{set}\right\} * 100\% \text{ -- (8a)}$$

$$\gamma\% = \left\{\left[PRR_{read} - PRR_{set}\right] / PRR_{set}\right\} * 100\% \text{ -- (8b)}$$

$$\eta\% = \left\{\left[RPR_{read} - RPR_{set}\right] / RPR_{set}\right\} * 100\% \text{ -- (8c)}$$

It should be noted here that in order to calculate $\pm\psi$ %, $\pm\lambda$, $\pm\chi$ % and $\pm\alpha$ %, $\pm\gamma$, $\pm\eta$ % the system requires to know the set (i.e. correct) discharge coefficient, the expansion coefficient, PPL coefficient, PLR, PRR and RPR values. As orifice plate meters are usually not calibrated it is necessary to derive these values from ISO 5167 Part 2 [1]. ISO states a discharge coefficient prediction in the form of the Reader-Harris Gallagher (RHG) equation. It should also be noted that ISO 5167 also offers a prediction for the PLR (see equation 9). From consideration of equation 1a we can then derive associated values for the PRR & RPR as shown is equations 10 & 11 respectively.

$$PLR = \frac{\sqrt{1 - \left\{\beta^4\left(1 - C_d^2\right)\right\}} - C_d\beta^2}{\sqrt{1 - \left\{\beta^4\left(1 - C_d^2\right)\right\}} + C_d\beta^2} \text{ -- (9)}$$

$$PRR = 1 - PLR \text{ -- (10)}, \qquad RPR = \frac{PRR}{PLR} \text{ -- (11)}$$

Furthermore, it can be shown that from initial standards knowledge of the discharge coefficient and the PLR the expansion and PPL coefficients can be found as shown by equations 12 & 13. Therefore, from the standards discharge coefficient and PLR predictions the expansion coefficient, PPL coefficient, PRR and RPR can be deduced. Unfortunately, ISO gives no uncertainty value with the PLR prediction.

$$K_r = \frac{\varepsilon C_d}{\sqrt{1 - PLR}} \text{ -- (12)} \qquad K_{ppl} = \frac{E\beta^2\varepsilon C_d}{\sqrt{PLR}} \text{ -- (13)}$$

$$\text{where } \beta = \sqrt{\frac{A_t}{A}} \text{ -- (14)}$$

<u>An orifice meter with a downstream pressure tap can produce six meter parameters with nine associated uncertainties.</u> These six parameters are the discharge coefficient, expansion flow coefficient, PPL coefficient, PLR, PRR and RPR. The nine uncertainties are the six parameter uncertainties (±x%, ±y%, ±z%, ±a%, ±b% & ±c%) and the three flow rate inter-comparison uncertainties ($\pm\phi$ %, $\pm\xi$, $\pm\nu$ %). ***These fifteen parameters define the DP meters correct operating mode***. Any deviation from this mode beyond the acceptable uncertainty limits is an indicator that there is an orifice meter malfunction and the traditional meter flow rate output is therefore not trustworthy. Table 1 shows the six possible situations that should signal a warning. Note that each of the six diagnostic checks has normalized data, i.e. each meter diagnostic parameter output is divided by the allowable difference for that parameter.

For practical real time use, a graphical representation of the meters health continually updated on a control room screen could be simple and effective. However, any graphical representation of must be accessible and understandable at a glance by any meter operator. Therefore, it has been proposed that three points be plotted on a normalized graph (see Figure 2). This graphs axis have no dimensions, they are number lines only. The normalized flow rate difference can be plotted on the abscissa (i.e. x-axis). The normalized DP ratio difference can be plotted on the ordinate (i.e. y-axis).

DP Pair	No Alarm	ALARM
ΔP_t & ΔP_{PPL}	$\lvert\psi\%/\phi\%\rvert \le 1$	$\lvert\psi\%/\phi\%\rvert > 1$
ΔP_t & ΔP_r	$\lvert\lambda\%/\xi\%\rvert \le 1$	$\lvert\lambda\%/\xi\%\rvert > 1$
ΔP_{PPL} & ΔP_r	$\lvert\chi\%/\upsilon\%\rvert \le 1$	$\lvert\chi\%/\upsilon\%\rvert > 1$
ΔP_t & ΔP_{PPL}	$\lvert\alpha\%/a\%\rvert \le 1$	$\lvert\alpha\%/a\%\rvert > 1$
ΔP_t & ΔP_r	$\lvert\gamma\%/b\%\rvert \le 1$	$\lvert\gamma\%/b\%\rvert > 1$
ΔP_{PPL} & ΔP_r	$\lvert\eta\%/c\%\rvert \le 1$	$\lvert\eta\%/c\%\rvert > 1$

Table 1. The diagnostic analysis

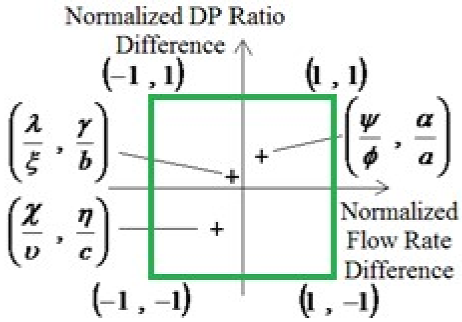

Fig 2. A NDB with normalized diagnostic result.

These normalized values have no units. On this graph a normalized diagnostic box (or "NDB") can be superimposed with corner co-ordinates: (1, 1), (1, −1), (−1, −1) & (−1, 1). On such a graph three meter diagnostic points can be plotted, i.e. $(\psi/\phi, \alpha/a)$, $(\lambda/\xi, \gamma/b)$ & $(\chi/\upsilon, \eta/c)$. That is, the three DP's have been split into three DP pairs and for each DP pair the difference in the two flow rate predictions and, separately, the difference in the actual to set DP ratio are being compared to their maximum allowable differences. If all points are within or on the NDB (as shown in Figure 2) the meter operator sees no metering problem and the traditional meters flow rate prediction can be trusted. However, if one or more of the three points falls outside the NDB the meter operator has a visual indication that the meter is ***not*** operating correctly and that the meters traditional (or any) flow rate prediction cannot be trusted. Furthermore, when a problem is indicated further analysis of the diagnostics can result in further information being learned regarding the nature of the problem.

A seventh diagnostic method was added by DP Diagnostics / Swinton Technology to the NDB plot in 2012. Equation 1 holds true for all generic DP meters. Equation 1 is a consequence of the first law of thermodynamics and as such it cannot be violated, even if a DP meter has malfunctioned. Therefore, when the three DP's are read from the meter, if equation 1 **appears** not to hold there is only one conclusion. As the first law of thermodynamics states it **must** hold, any indication that it does not is an **absolute statement by the diagnostic system that there is an erroneous DP reading coming from the instrumentation** (regardless of whether the meter body is serviceable or not).

$$\Delta P_{t,\inf} = \Delta P_r + \Delta P_{PPL} \quad \text{--- (1b)}$$

A DP meter reading all three DP's can infer the traditional DP (ΔP_t) by summing the read recovery DP (ΔP_r) and permanent pressure loss (ΔP_{PPL}), as shown by equation 1b. This gives an inferred traditional DP ($\Delta P_{t,\inf}$) that can be compared to the directly read traditional DP (ΔP_t). Whereas theoretically these values are the same, due to the uncertainties associated with three correctly operating DP transmitters they will be slightly different. The percentage difference ($\delta\%$) can be calculated as seen in equation 15.

$$\delta\% = \{(\Delta P_{t,\inf} - \Delta P_t)/\Delta P_t\} * 100\% \quad \text{--- (15)}$$

This $\delta\%$ value can be normalized by dividing it by the allowable percentage difference between the values ($\theta\%$). It is possible to calculate a precise uncertainty for this normalization from the DP transmitter manuals and the read DP values. However, it has been found in practice that setting $\theta\% = 1\%$ is a reasonable practical value that covers a wide range of DP's measured. If this normalized value is less than unity then no problem is found with the DP measurements. If this normalized value is greater than unity then a problem is found with the DP measurements. Table 2 shows the single situation that should signal a DP measurement warning.

DP Pair	No Warning	WARNING
$\Delta P_{t,\inf}$ & ΔP_t	$\delta\% / \theta\% \le 1$	$\delta\% / \theta\% > 1$

Table 2. The DP reading possible diagnostic results.

This seventh diagnostic calculation can be added to the NDB plot. Unlike the diagnostics described above, this diagnostic result is singular and hence not a (x, y) co-ordinate on Cartesian graph, but rather a point on a number line, where the point must fall within the range: $-1 \le \delta\%/\theta\% \le +1$. However, we can still use the NDB presentation by setting y = 0, and then adopting the x-axis as a number line. This plot gives a DP measurement diagnostic result on the x-axis such that if the point remains inside the NDB there is no warning, and if the point is outside the NDB there is a DP reading integrity warning. Figure 3 shows the updated NDB plot with the DP measurement check included. Such a plot allows the meter operator to not only see a malfunction but be able to distinguish the malfunction between a DP instrumentation malfunction and another malfunction (such as a meter malfunction or a flow computer keypad entry error).

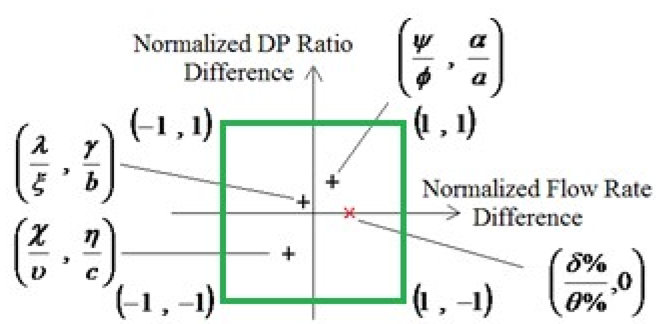

Fig 3. A normalized diagnostic box with normalized diagnostic results, DP measurement check included.

The CIATEQ Orifice Meter Set Up

In August 2012 DP Diagnostics installed Prognosis on a CIATEQ 4", sch 40, 0.5 beta ratio orifice meter. The flowing fluid was water at atmospheric pressure and temperature. Figure 4 shows a photograph of the CIATEQ single chamber orifice meter initial set up. (In the particular test of a buckled orifice plate due to problems fitting and removing the plate from a chamber a paddle plate design with flange taps was used.)

Figure 4. CIATEQ 4" water flow facility with an orifice meter diagnostic ready.

The Prognosis software standard default uncertainty settings for were used, i.e. x=1%, y=2.5%, z=2.5%, a=3%, b=2.5%,c=4% $\theta = 1\%$.

Discussion and Results of Tests

The water flow facility was run at 500 kg/min. The orifice meter with Prognosis and the water facilities reference meter (an Endress & Hausser Coriolis meter) matched well within the meters uncertainties. The orifice meter was operating correctly.

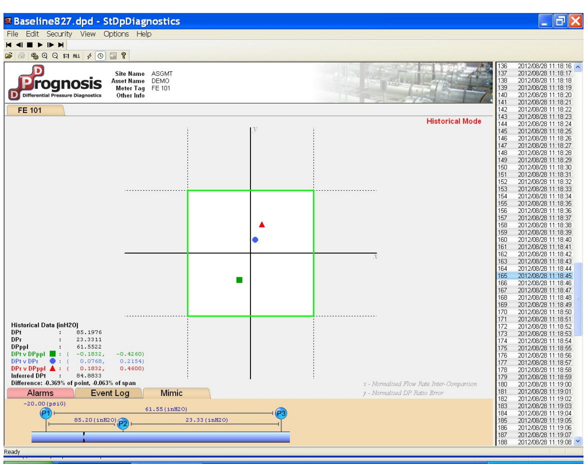

Figure 5. Prognosis Screenshot from the Correctly Operating Orifice Meter.

A screen shot from Prognosis with the correctly operating meter is shown in Figure 5. Note that the fourth diagnostic point is not included in this first edition of the software. However, the diagnostic check itself is included in the first edition of the software, it simply isn't shown as a fourth point on the NDB. The read traditional DP (85.2"WC), recovered DP (23.3"WC) and PPL (61.6"WC) are presented at the bottom left corner above the three points co-ordinates. Below these three co-ordinates is the calculated inferred traditional DP. The "Difference" stated below this inferred DP is the DP integrity diagnostic. In this case the difference between the read and inferred traditional DP is -0.369% (which is <1% and therefore okay). Unfortunately, due to the required format of this paper the screenshots are too small for this to be seen, but it is there. The fourth point is simply the plotting on the x-axis of this "difference" value. In this example the DPs were found to be read correctly.

A Leaking Five Way Manifold on the Traditional DP Transmitter

One common malfunction of an orifice meter is the DP transmitter having the equalization valve on a five way manifold not properly shut or damaged, i.e. leaking between the high and low pressure ports. This causes a DP reading error. If the leak is not excessive it is likely the operator will not see the problem by conventional methods. Prognosis will see this problem.

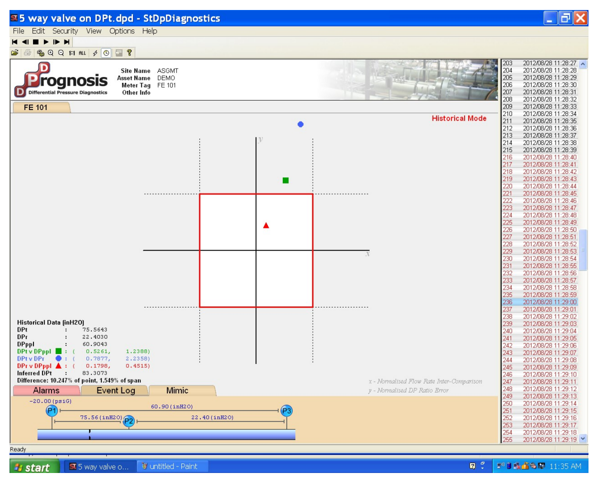

Figure 6. A Leaking Five Way Manifold on the Traditional DP Transmitter.

With the steady flow that produced the baseline results of Figure 5, the DP transmitter reading the traditional DP had the equalization valve cracked open. The DP dropped from the correct 85.2"WC to 75.6"WC. The DP then remained steady at approximately 75.6"WC, with the meter predicting a flow rate that had approximately a -5.5% bias. The Prognosis response is shown in Figure 6. The DP integrity diagnostic, showed a big problem with a 10.2% result, i.e. >> 1%. Prognosis is stating the DP's are **not** trustworthy. Furthermore, the two of the three diagnostic points are outside the NDB. The one point inside the NDB, i.e.

showing no problem, is the point that does not use the DP transmitter that measures the traditional DP. The other two points outside the NDB both use the DP transmitter that is measuring the traditional DP. Hence, we know the meter has malfunctioned, we know the reason is the DP readings and we know that it is the traditional DP reading that is erroneous. Furthermore, we know that the other two DP readings, i.e. that of the recovered DP and PPL are correct. Hence, we know the inferred traditional DP of 83.3”WC is trustworthy. Therefore, we know the meter has a problem, we know what problem, what the level of error is and what the correct flow rate is. Without Prognosis there is no internal diagnostics to even show the meter has a problem.

A Leaking Five Way Manifold on the Recovered DP Transmitter

Once the leaking five way manifold example for the traditional DP reading was complete, the valve was closed and CIATEQ witnessed the points returning inside the NDB while the “difference” value reduced to an average < 1%. Once this correct operation baseline was returned to the DP transmitter reading the recovered DP had its equalization valve cracked open. This would not cause a flow rate prediction error as it doesn’t affect the traditional DP reading. However, a diagnostic system must be able to distinguish between the meter malfunctioning and itself malfunctioning.

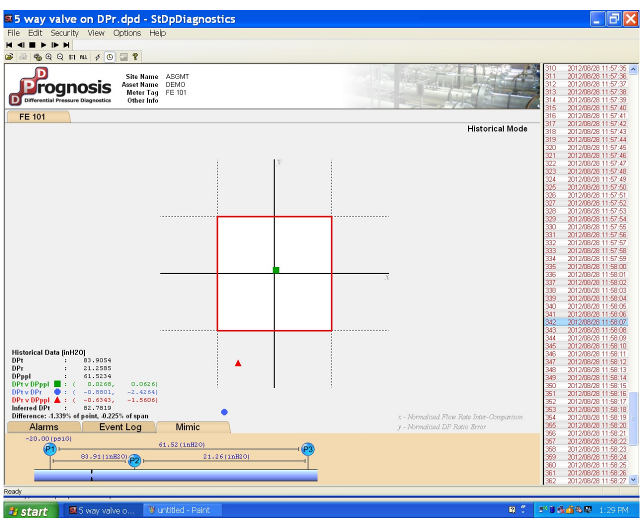

Figure 7. A Leaking Five Way Manifold on the Recovered DP Transmitter.

The traditional DP stayed steady at 83.9”WC. The recovered DP reading dropped from 23.3”WC to 21.3”WC. Figure 7 shows the response of Prognosis. The DP integrity diagnostic, i.e. the “difference”, showed a problem with a -1.33% result, i.e. > 1%. Prognosis is stating the DP’s are **not** trustworthy. Furthermore, the two of the three diagnostic points are outside the NDB. The one point inside the NDB, i.e. showing no problem, is the point that does not use the recovered DP transmitter. The other two points outside the NDB both use the DP transmitter that is measuring the recovered DP. Hence, we know the system has malfunctioned, we know the reason is the DP readings and we know that it is the recovered DP reading that is erroneous. Hence, we know the DP transmitter reading the traditional DP is still serviceable, we know then that the DP meter is still serviceable, but the diagnostic system needs maintenance for the recovered DP transmitter. Once this test was complete the equalization valve on the recovered DP transmitter was closed and CIATEQ witnessed the points returning inside the NDB while the “difference” value reduced to an average < 1%.

Drifting or Incorrectly Calibrated DP Transmitters

A drifting or incorrectly calibrated DP transmitter has the same end result, the DP being measured incorrectly. Starting from the baseline correct operation of the orifice meter the traditional DP transmitter’s calibration was deliberately changed to simulate the effect of a wrong calibration or a drifting transmitter. In Figures 8 and 9 the DP transmitter reading the traditional DP has had the correct DP associated with its 4-20mA calibration slightly changed to produce a slightly low and then high DP reading.

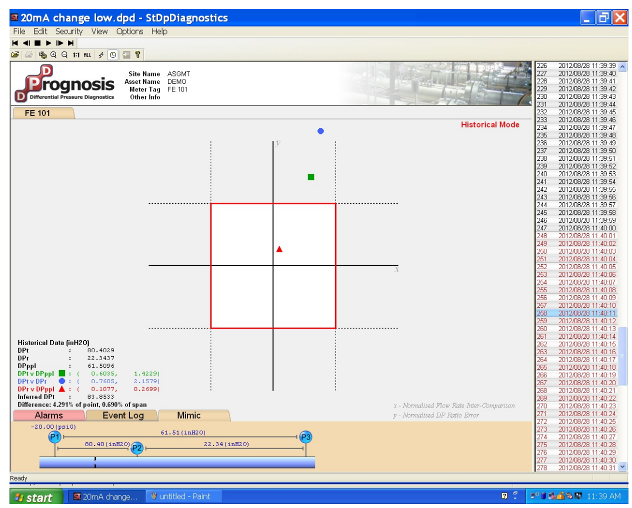

Figure 8. Traditional DP Transmitter with Drift / or Incorrect Calibration, Reading DP low.

In Figure 8 the correct DP of 85”WC has been changed to 80.4”WC, producing a flow rate error of approximately -2.7%. The DP integrity diagnostic indicated a problem with a +5.3% result, i.e. > 1%. Prognosis is stating the DP’s are **not** trustworthy. Furthermore, the two of the three diagnostic points are outside the NDB. The one point inside the NDB, i.e. showing no problem, is the point that does not use the DP transmitter reading the traditional DP. The other two points outside the NDB both use the DP transmitter that is measuring the traditional DP. Hence, we know the system has malfunctioned, we know the reason is the DP readings and we know that it is the traditional DP reading that is erroneous. We know the other two DP readings are trustworthy. Hence, we know the inferred traditional DP is trustworthy so we know the correct flow rate.

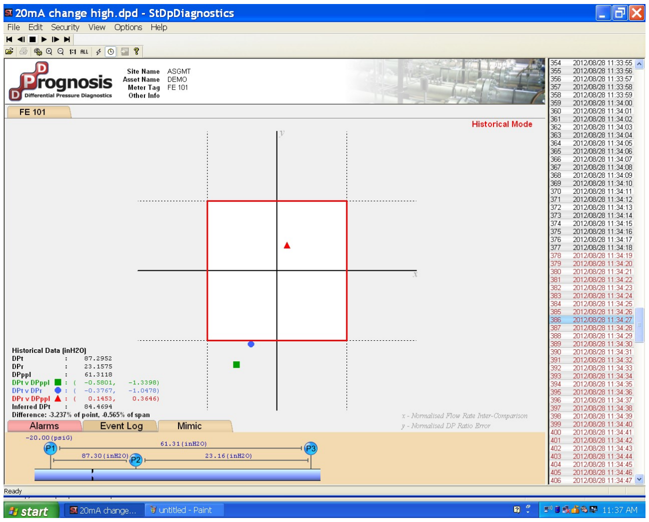

Figure 9. Traditional DP Transmitter with Drift / or Incorrect Calibration, Reading DP High.

In Figure 9 the correct DP of 85"WC has been changed to 87.3"WC, producing a flow rate error of approximately +1.3%. The DP integrity diagnostic indicated a problem with a -2.6% result, i.e. > 1%. Prognosis is stating the DP's are **not** trustworthy. Furthermore, the two of the three diagnostic points are outside the NDB. The one point inside the NDB, i.e. showing no problem, is the point that does not use the DP transmitter reading the traditional DP. The other two points outside the NDB both use the DP transmitter that is measuring the traditional DP. Hence, we know the system has malfunctioned, we know the reason is the DP readings and we know that it is the traditional DP reading that is erroneous. We know the other two DP readings are trustworthy. Hence, we know the inferred traditional DP is trustworthy so we know the correct flow rate.

A Buckled Plate

Figure 10 shows the buckled / warped plate used at the CIATEQ flow facility to check Prognosis.


Figure 10. Buckled (or "Warped") Orifice Plate Tested by CIATEQ

For the same 500 kg/min of the earlier baseline Figure 11 shows a screenshot of the Prognosis result for a buckled plate. Note that the DP has dropped from the approximate 85"WC an undamaged 0.5 beta ratio plate would produce to 72"WC.

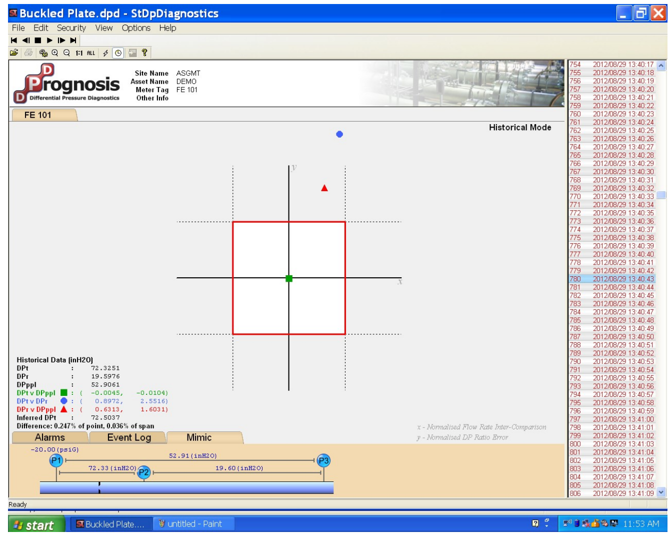

Figure 11. A Buckled Orifice Plate

This is a flow rate prediction error of approximately -8%. The DP integrity test showed the DP readings are correct with a registered "difference" of 0.25%. Prognosis therefore showed that the meter had no DP reading problem but a significant meter body problem. The plot is indicative of a buckled orifice plate. Traditionally there are no orifice meter diagnostics that can monitor for such a problem.

Incorrect Orifice Diameter Keypad Values

Once the undamaged orifice plate was re-installed Prognosis again showed no problem existed. With this baseline start, too high and then too low an orifice diameter was keypad entered into the flow computer. First, the actual orifice diameter of 2.0128" has been replaced by 2.128", i.e. the "0" has been missed to simulate a typographical error. The resulting flow rate error is approximately +12.5%.

Figure 12 shows a screenshot of the Prognosis result. The DP integrity check showed the DP readings were correct with a registered "difference" of 0.28%, i.e. <1%. However, all three points are outside the NDB signaling a significant flow rate prediction error caused by a problem with the meter body. In this case the meter is not the size the flow computer has been told! The pattern of the points in the NDB correctly suggest that the flow rate bias is positive.

Next, the actual orifice diameter of 2.0128" has been replaced by 1.9", i.e. approximately the opposite of the above scenario. The resulting flow rate error is approximately -11.5%. Figure 13 shows a screenshot of the Prognosis result. The DP integrity check showed the DP readings are correct with a registered "difference" of -0.67%,

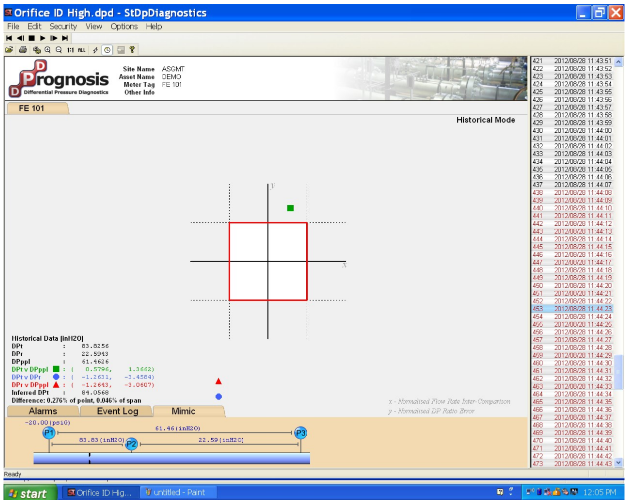

Figure 12. Orifice Diameter too Large 2.128” (Nominal 2.0128”)

i.e. <1%. However, all three points are outside the NDB signaling a significant flow rate prediction error caused by a problem with the meter body. In this case the meter is not the size the flow computer has been told! The pattern of the points in the NDB correctly suggest that the flow rate bias is negative.

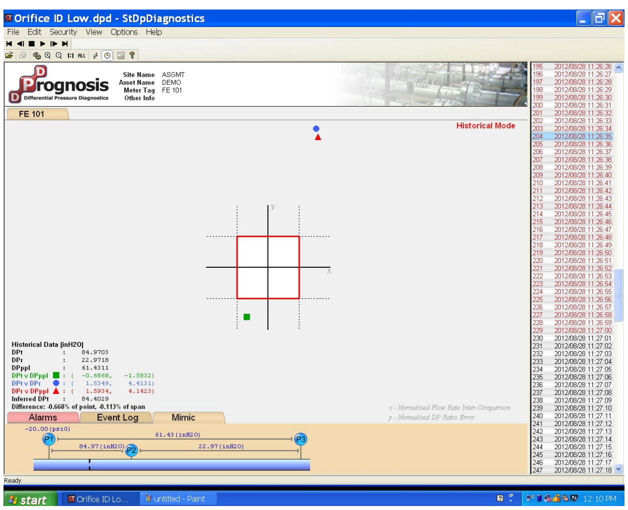

Figure 13. Orifice Diameter Too Low 1.9” (Nominal 2.0128”)

Incorrect Inlet Diameter Keypad Values

Once the orifice diameter value in the flow computer was returned to the correct value Prognosis again showed no problem existed. With this baseline start, too high and then too low an inlet diameter was keypad entered into the flow computer. First, the actual inlet diameter of 4.0044” has been replaced by 4.1”. Figure 14 shows a screenshot of the Prognosis result. The DP integrity check showed the DP readings were correct with a registered “difference” of -0.64%%, i.e. <1%. However, two of the three points were outside the NDB signaling a significant flow rate prediction error caused by a problem with the meter body. In this case

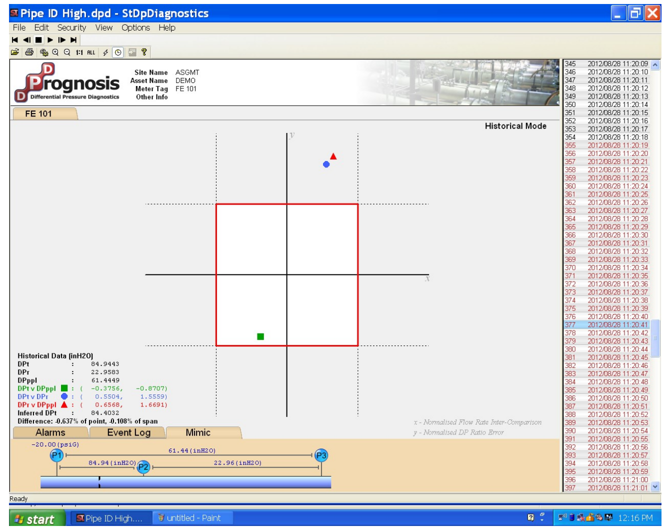

Figure 14. Inlet Diameter too Large 4.1” (Nominal 4.0044”)

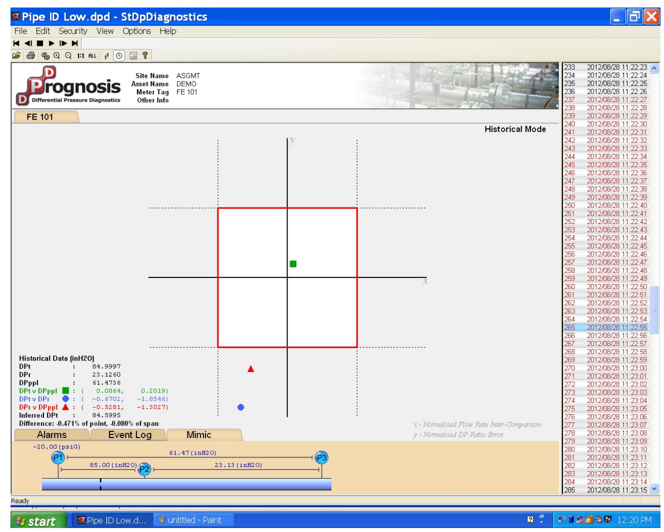

Figure 15. Inlet Diameter too Small 3.9” (Nominal 4.0044”)

the meter was not the size the flow computer has been told! The NDB pattern correctly suggests a negative flow rate prediction error.

Next, the actual inlet diameter of 4.0044” was replaced by 3.9”, i.e. approximately the opposite of the above scenario. Figure 15 shows a screenshot of the Prognosis result. The DP integrity check showed the DP readings were correct with a registered “difference” of -0.47%, i.e. <1%. However, two of the three points were outside the NDB signaling a significant flow rate prediction error caused by a problem with the meter body. In this case the meter was not the size the flow computer has been told! The NDB pattern correctly suggests a positive flow rate prediction error.

A Reversed (or “Backwards”) 0.5 Beta Ratio Orifice Plate

For an approximate steady flow of 515 kg/min Figure 16 shows a screenshot of the Prognosis result for a reversed plate. The DP dropped from the approximate 90.5”WC for a correctly installed 0.5 beta ratio plate to 65.5"WC. This was a flow rate prediction error of approximately -14%. The DP integrity test showed the DP readings correct with a registered "difference" of -0.55%, i.e. < 1%. Figure 16 showed that the meter has no DP reading problem but a significant meter body problem. Two of the three diagnostic points are outside the NDB. The plot is indicative of a reversed orifice plate. Traditionally there are no orifice meter diagnostics that can monitor for such a problem.

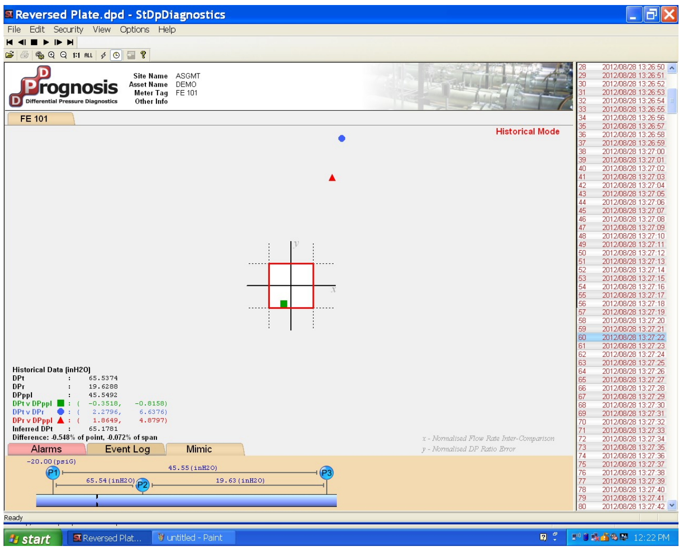

Figure 16. A Reversed Plate.

A Damaged Orifice Edge

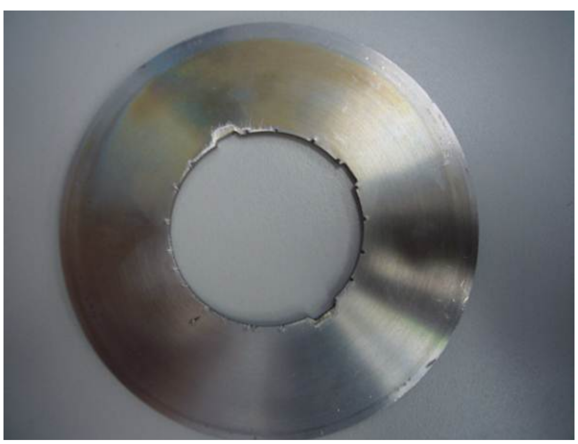
Figure 17. Damaged Orifice Plate

Figure 17 shows substantial damage done to an orifice plate. For an approximate steady flow of 500 kg/min Figure 18 shows a screenshot of the Prognosis result for this damaged plate test. The DP dropped from the approximate 85"WC for an undamaged 0.5 beta ratio plate to 77.45"WC. This is a flow rate prediction error of approximately -4%. The DP integrity test showed the DP readings were correct with a registered "difference" of +0.37%, i.e. < 1%. Figure 18 showed that the meter had no DP reading problem but a significant meter body problem. Two of the three diagnostic points are outside the NDB. The NDB plot suggests the meter body problem is causing a negative bias on the flow rate prediction. Traditionally there are no orifice meter diagnostics that can monitor for such a problem.

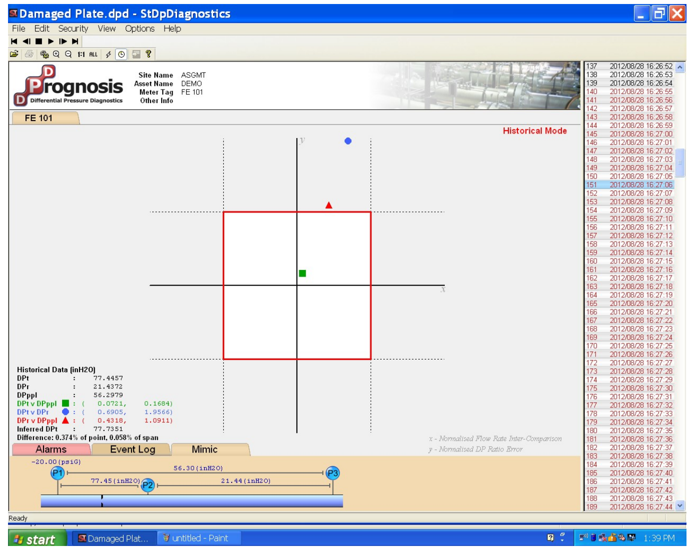

Fig 18. An Orifice Plate with a Damaged Edge.

Partial Blockage of an Orifice Plate

Figure 19 shows a "half moon orifice plate". This mimics an orifice plate with a partial blockage. CIATEQ installed this in the orifice meter with Prognosis. The blockage was at top dead center.


Figure 19. Back Face View of a Half Moon Orifice Plate Mimicking Partial Blockage of an Orifice.

The blockage very significantly increases the flow velocity through the meter and causes substantially higher DPs. The blockage therefore induces large positive flow rate prediction errors. As the DP's are so high the test at CIATEQ required that the flow rate be substantially reduced from the approximately 500 kg/min used for most of these tests in order to avoid saturating the DP transmitters. The flow rate was varied until the traditional DP was approximately 250"WC (on a DP transmitter that had a URL of 400"WC). Unfortunately, the actual flow rate that produced this DP was not recorded. It is therefore not possible to state a flow rate error value. However, it is clear that the flow rate prediction error is a very substantial positive error.

Figure 20 shows a screenshot of the Prognosis result for this partially blocked plate test. The DP integrity test showed the DP readings correct with a registered “difference” of -0.4%, i.e. < 1%. Figure 20 showed that the meter has no DP reading problem but a significant meter body problem. All three diagnostic points are well outside the NDB. The NDB plot therefore shows that there was a meter malfunction and a potentially large flow rate error associated with a meter body problem. The diagnostic pattern on the NDB correctly suggested that there is a very substantial positive flow rate error. Traditionally there are no orifice meter diagnostics that can monitor for such a problem.

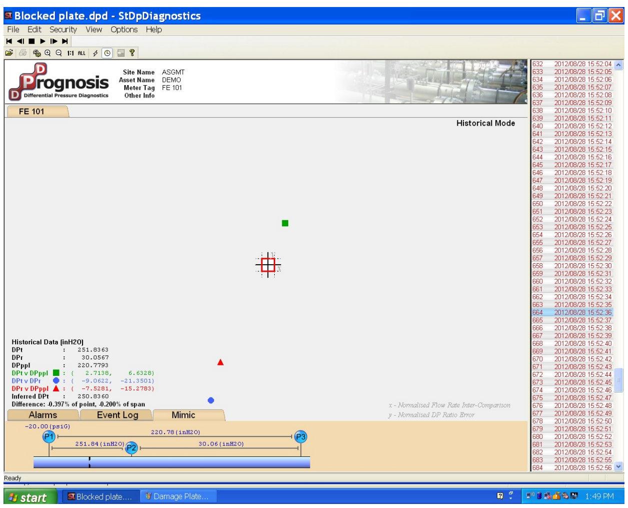

Fig 20. A Partial Blockage of the Orifice

Conclusions

The CIATEQ water flow tests on a 4”, sch 40, 0.5 beta ratio orifice meter have shown that the diagnostic principles on which Prognosis is based are sound and work as described. This diagnostic system offers the first and only internal comprehensive diagnostic system for generic DP meters, including orifice meters.

Prognosis has the ability to show meter malfunctions occurring in real time, or when reviewing historical archived data, when in the past a malfunction occurred. This then can protect the operator against flow rate mis-measurement and can reduce needless scheduled maintenance. Furthermore, when Prognosis indicates maintenance is indeed required the technician does not go to the meter “blind”. Prognosis not only states that the meter has a problem, it can identify if the problem is with the DP transmitters or the meter body. If the problem is with the instruments Prognosis will state which instrument and has redundancy to cover for that failure. If the problem is with the meter body Prognosis can short list the problems that could cause the diagnostic result while discounting the malfunctions that could not cause that particular diagnostic result. This then greatly simplifies and shortens the maintenance process.

Prognosis is a good addition to orifice meter systems both to avoid orifice meter malfunctions going unnoticed, and for greatly simplifying the maintenance procedure required to fix the orifice meter if and when it does malfunction.

Due tests were witnessed by members of Hydrocarbon National Commission (CNH, short in Spanish), Prognosis is considered now by this authority as an alternative to comply several clauses of Mexican regulation issued by CNH.

In various cases, in order to audit orifice plate metering systems according regulation emitted by CNH its necessary to stop operation of metering system in order to evaluate plate, meter tube, instrumentation, etc. Due capability of Prognosis to diagnostic metering systems on line (in operation), make very attractive and practical its use to comply CNH regulation.

References

[1]. International Standard Organisation, “Measurement of Fluid Flow by Means of Pressure Differential Devices, Inserted in circular cross section conduits running full”, no. 5167, 2003.

[2]. Skelton, M. “Developments in the Self-Diagnostic Capabilities of Orifice Plate Meters”, 28th International North Sea Flow Measurement Workshop, October 2010.

[3]. Steven, R. “Diagnostic Methodologies for Generic Differential Pressure Flow Meters”, North Sea Flow Measurement Workshop October 2008, St Andrews, Scotland, UK.

[4]. Steven, R. “Significantly Improved Capabilities of DP Meter Diagnostic Methodologies”, North Sea Flow Measurement Workshop October 2009, Tonsberg, Norway.

[5]. Moncada D., Steven R. “ Resultados de Pruebas de un Sistema de Diagnostico de Medición por Placa de Orificio en laboratorio de flujo de CIATEQ”, Congreso Mexicano del Petróleo, Junio 2013. Cancún, México