# Orifice meter diagnostics laboratory tests & field tests

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**Información del artículo: recibido: diciembre de 2015-aceptado: enero de 2016**

## Abstract

A comprehensive orifice meter diagnostic system called 'Prognosis' has been developed. This system has been tested over several years in multiple laboratory and field applications. It is now used by multiple hydrocarbon production companies world wide. This paper describes the theory, the user interface and shows laboratory test results from CIATEQ in Mexico, CEESI in Colorado, USA and field test results from ConocoPhillips Franklin Gas Station in Texas, USA.

**Keywords**: Orifice meter, diagnostics, Prognosis.

## Introduction

In 2009 DP Diagnostics LLC (DPD) disclosed a proprietary comprehensive Differential Pressure (DP) meter diagnostic system concept, (see Steven [1]). In 2010 Swinton Technology Ltd (ST) partnered with DPD to produce the DP meter diagnostic system 'Prognosis'. This system operates on all DP meter including orifice meters. The system used with orifice meters has been developed and tested on multiple test laboratories and field trails. In this paper the theory and user interface is described along with a 2012 orifice meter laboratory test (at the CIATEQ flow facility in Mexico), 2009 orifice meter laboratory test (at CEESI in Colorado, USA), and a 2012 orifice meter field trial (at the ConocoPhillips Franklin Gas Station in Texas, USA).

## Orifice meter diagnostics theory of operation

An overview of these patented 'pressure field monitoring' diagnostics is now given. For details the reader should refer to descriptions given by Steven et al [1,2,3], Skelton [4] & Rabone et al [5].

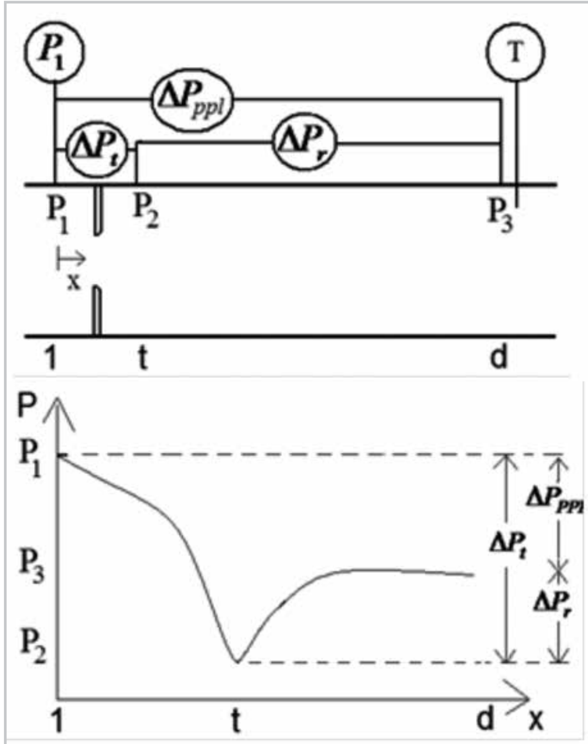


**Figure 1.** Orifice meter with instrumentation sketch and pressure field graph.

**Figure 1** shows a sketch of a generic DP meter and its pressure field. The DP meter has a third pressure tap downstream of the two traditional pressure ports. (This is ideally located 6D downstream of the plate.) This allows three DPs to be read, i.e. the traditional ($\Delta P_t$), recovered ($\Delta P_r$) and permanent pressure loss ($\Delta P_{PPL}$) 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 (dictated by the transmitter uncertainties) 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. Symbols $f_t$, $f_r$ & $f_{PLL}$ 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 mean square of the PPL & traditional meter uncertainties, ω%. The percentage difference of the expansion to traditional flow rate calculations is denoted as ƛ%. The allowable difference is the root mean square of the expansion & traditional meter uncertainties, ʒ%. The percentage difference of the expansion to PPL flow rate calculations is denoted as $x$%. The allowable difference is the root mean square of the expansion & $PPL$ meter uncertainties, $v$%.

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 sys%. The allowable difference is the expected PLR uncertainty, . The percentage difference of the read to expected PRR is denoted as . The allowable difference is the expected RPR uncertainty, . The percentage difference of the read to expected RPR is denoted as . The allowable difference is the expected RPR uncertainty, .

The three flow rate calculations and how to derive or infer all required diagnostic parameters from ISO 567 Part 2 [6], is all fully disclosed by Steven [1,2] & Skelton et al [3].

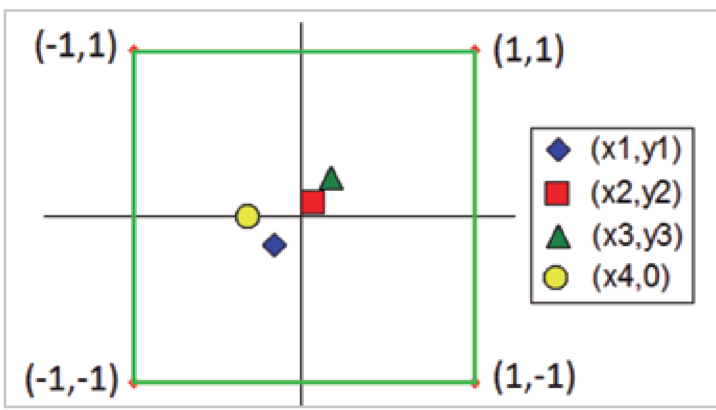


**Figure 2.** Normalized diagnostic box (NDB) with diagnostic results.

These seven diagnostic results can be shown on the operator interface as plots on a graph. That is, we can plot, **Figure 2**) the following four co-ordinates to represent the seven diagnostic checks:

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

The act of 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 2). This is the standard user interface with the diagnostic system. All four diagnostic points inside the NDB indicate a serviceable DP meter.

**Laboratort trials at the CIATEQ water flow facility**

In August 2012 the system was installed on a CIATEQ 4", sch 40, 0.5 beta ratio orifice meter. The flowing fluid was water at atmospheric pressure and temperature. **Figure 3** hows 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 designed with flange taps was used).

**Figure 3.** CIATEQ 4" water flow facility with an orifice meter diagnostic ready.

The system software standard default uncertainty settings were used, i.e. *x*=1%, *y*=2.5%, z=2.5%, a=3%, *b*=2.5%, *c* =4%. 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.

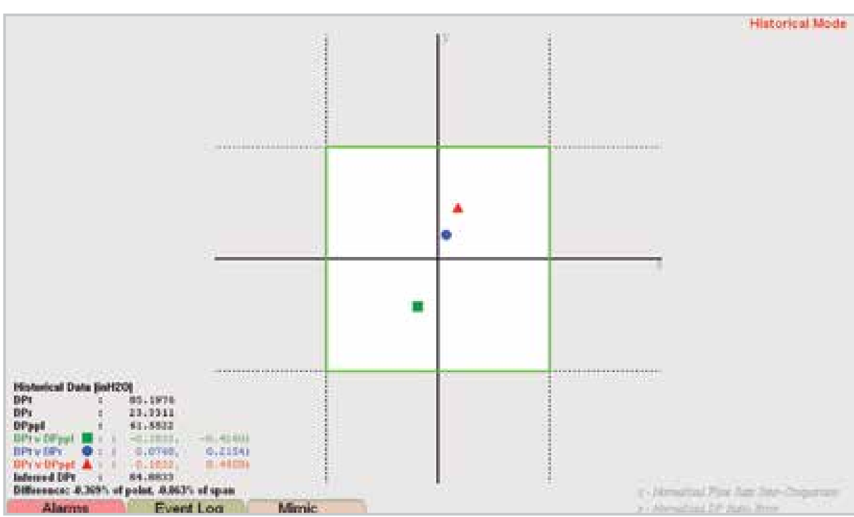


**Figure 4.** Prognosis screenshot from the correctly operating orifice meter.

A screen shot from the system with the correctly operating meter is shown in **Figure 4**. Note all points are inside the NDB indicating a serviceable orifice meter system. The fourth diagnostic point is not included in this first edition of the software. However, the diagnostic **check** is included. The bottom left of the screen shot shows a set of information including the 3 DP values measures, the plotted co-ordinate points, and the percentage difference of the read to inferred traditional DP (i.e. -0.369% in this case). The fourth point added in a later edition of software, representing the DP integrity check, is simply the co-ordinate (-0.369,0).

### 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.

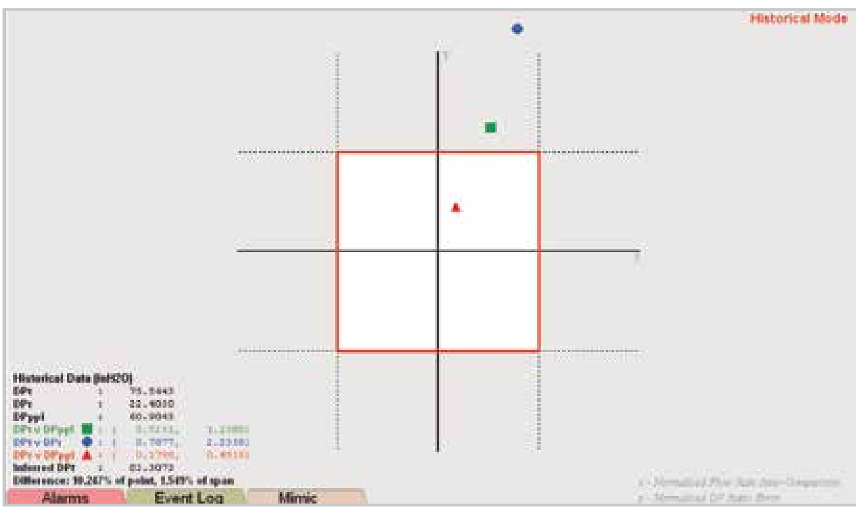


**Figure 5.** A leaking five way manifold on the traditional DP transmitter.

With the steady flow that produced the baseline results of Figure 4, 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 system response is shown in Figure 5. 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, the operator knows the metering system has malfunctioned; the reason is the DP readings and that it is the traditional DP reading that is erroneous. Furthermore, the operator knows that the other two DP readings, i.e. that of the recovered DP and PPL are correct. Hence, it is known that the inferred traditional DP of 83.3"WC is trustworthy. Therefore, the system indicated that the meter had a problem, what that particular problem was, what the level of error is and what the correct flow rate is. Without the system there is no internal diagnostics to 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 the points returning inside the NDB were witnessed while the "difference" value reduced to an average < 1%. Once correct operation was resumed 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.

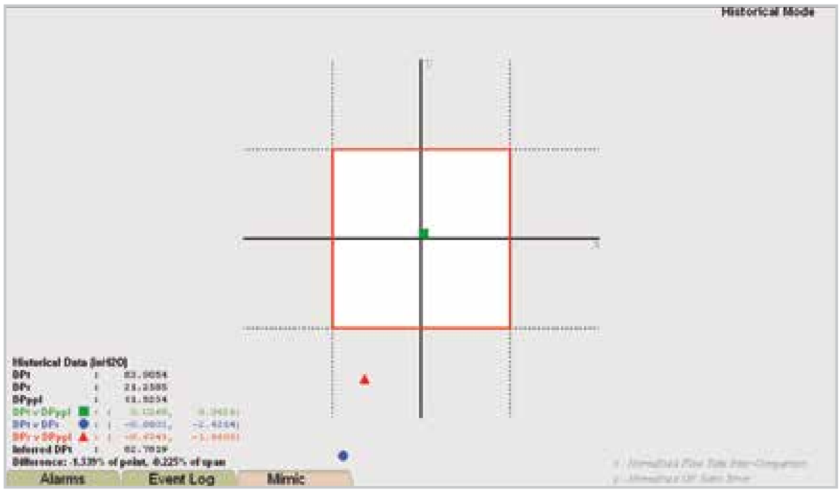


**Figure 6.** A leaking five way manifold on the recovered DP transmitter.

The traditional DP stayed steady at 83.9"WC. The recovered DP reading dropped from 23.3"WC to 21.3"WC. **Figure 6** shows the response of the system. The DP integrity diagnostic, i.e. the "difference", showed a problem with a -1.339% result, i.e. > 1%. The system is correctly stating the set of DP's read are **not** trustworthy. Furthermore, the two of the three diagnostic points are outside the NDB. The two points outside the NDB both use the DP transmitter that is measuring the recovered DP. Hence, the operator knows the system has malfunctioned; the reason is the DP readings and it is the recovered DP reading that is erroneous. The operator therefore knows the DP transmitter reading the traditional DP 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 the points returning inside the NDB were witnessed as the DP "difference" value reduced to an average < 1%.

### A drifting or incorrectly calibrated DP transmitter

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 7** & **8** the DP transmitter reading the traditional DP had the correct DP associated with its 4-20mA calibration, slightly changed to produce a slightly low and then high DP reading.

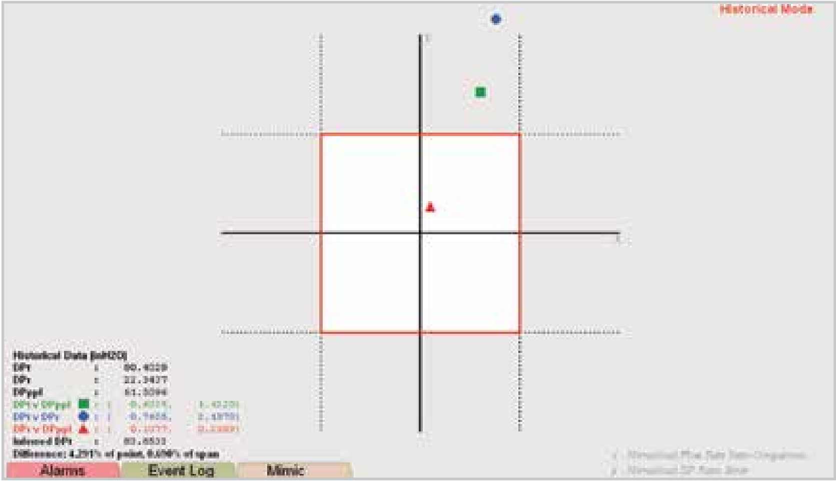


**Figure 7.** Traditional DP transmitter with drift / or incorrect calibration, reading DP low.

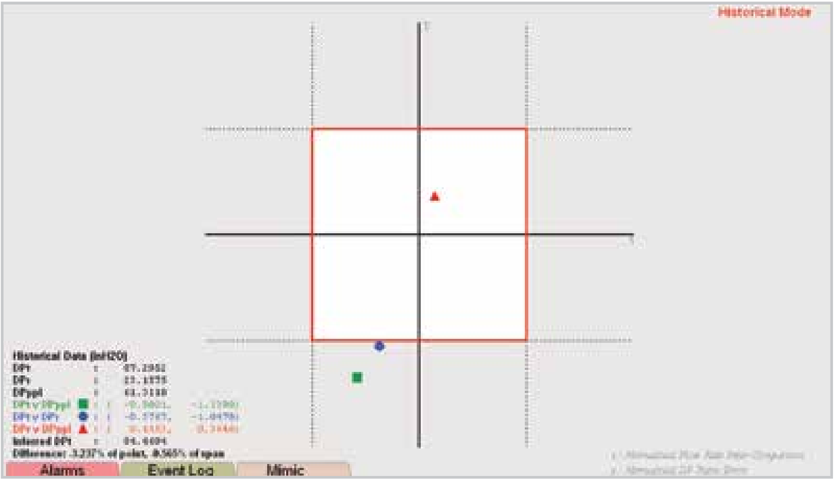


**Figure 8.** Traditional DP transmitter with drift / or incorrect calibration, reading DP high.

In **Figure 7** 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 +4.3% result, i.e. > ±1%. The system is stating the read DP set is **not** trustworthy. The two points outside the NDB both use the DP transmitter that is measuring the traditional DP. Hence, the operator knows that the system has malfunctioned, the reason is the DP readings, and it is the traditional DP reading that is erroneous. The other two DP readings are known to be trustworthy (as their diagnostic point is inside the NDB), allowing the traditional DP and hence the flow rate to be correctly inferred.

In **Figure 8** 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 -3.2% result, i.e. > ±1%. The orifice meter diagnostic system is stating the DP's are **not** trustworthy. The two points outside the NDB use the DP transmitter that is measuring the traditional DP. Hence, the operator knows the system has malfunctioned, the reason is the DP readings, and it is the traditional DP reading that is erroneous. The other two DP readings are known to be trustworthy (as their diagnostic point is inside the NDB) allowing the traditional DP and hence the flow rate to be correctly inferred.

**A buckled (i.e. 'Warped') orifice plate**

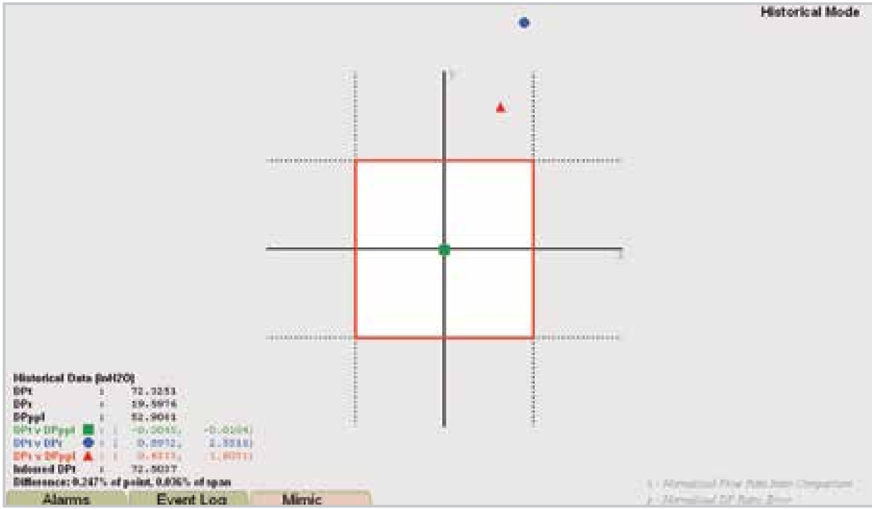


**Figure 9.** 4", 0.5ß buckled paddle plate orifice meter.

**Figure 10.** Buckled (or "Warped") orifice plate tested.

**Figure 10** shows the buckled / warped paddle plate used at the flow facility to check the response of the orifice meters diagnostic system. For the same 500 kg/min of the earlier baseline **Figure 9** shows a screenshot of the Prognosis result for this buckled plate. The DP has dropped from the approximate 85"WC an undamaged 0.5 beta ratio plate would produce to the 72"WC produced by this buckled 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%. The orifice meter system 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**

Starting with a correctly operating orifice meter (with the system showing all points inside the NDB), too high and then too low an orifice diameter was then keypad entered into the flow computer.

First, the actual orifice diameter of 2.0128” was set in the flow computer (and hence Prognosis) as 2.128”, i.e. the “0” has been missed to simulate a typographical error. The resulting flow rate error is approximately +12.5%. **Figure 11** shows a screenshot of the results. The DP integrity check showed the DP readings were correct with a registered “difference” of 0.276%, 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 actual meter size is different to that supplied to the flow computer.

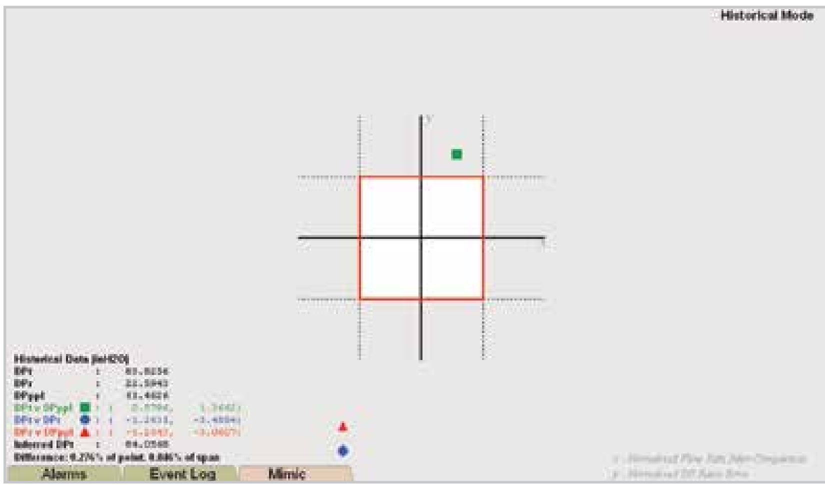


**Figure 11.** Orifice Diameter too Large 2.128”, (Nominal 2.0128”).

The actual orifice diameter of 2.0128” was then set in the flow computer (and hence the system) as 1.9”, i.e. approximately the opposite of the first scenario. The resulting flow rate error is approximately -11.5%. **Figure 12** shows a screenshot of the results. The DP integrity check showed the DP readings are correct with a registered “difference” of -0.67%, 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.

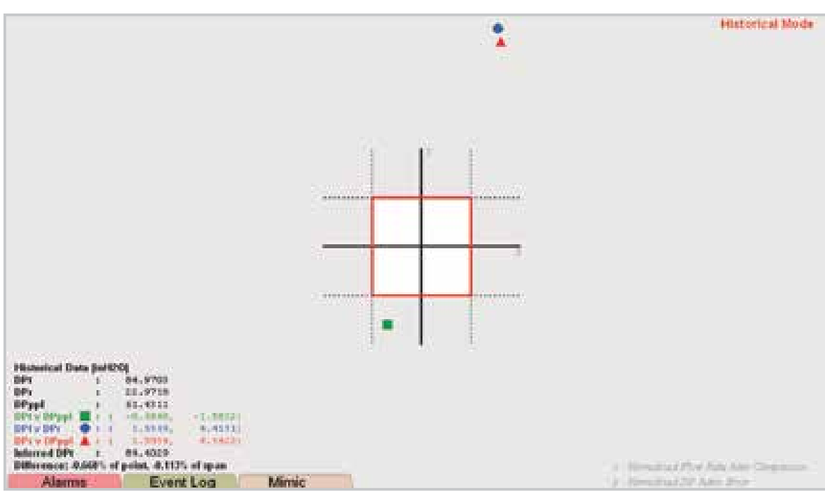


**Figure 12.** Orifice Diameter Too Low 1.9” (Nominal 2.0128”).

### Incorrect inlet diameter keypad values

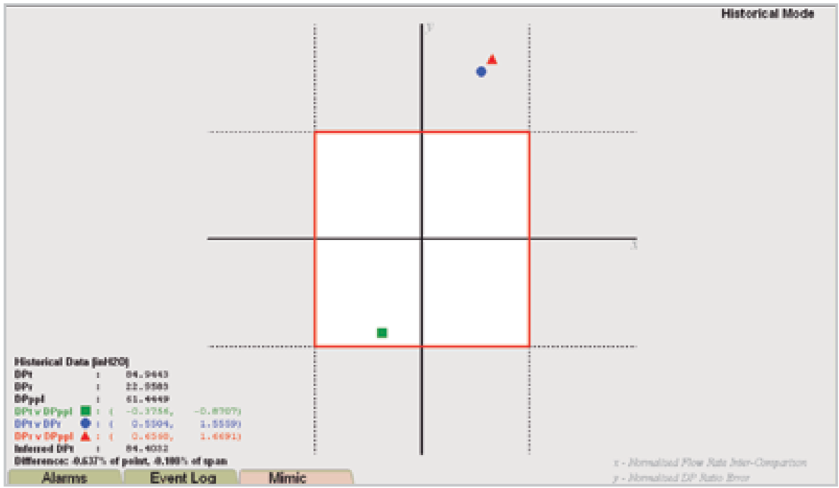


**Figure 13.** Inlet diameter too large 4.1” (Nominal 4.0044”).

Starting with a correctly operating orifice meter (with Prognosis showing all points inside the NDB) too high and then too low an inlet diameter was then keypad entered into the flow computer. First, the actual inlet diameter of 4.0044” was then set in the flow computer (and hence the system) as 4.1”. **Figure 13** shows a screenshot of the system result. The DP integrity check showed the DP readings were correct, with a registered “difference” of -0.637%%, 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.

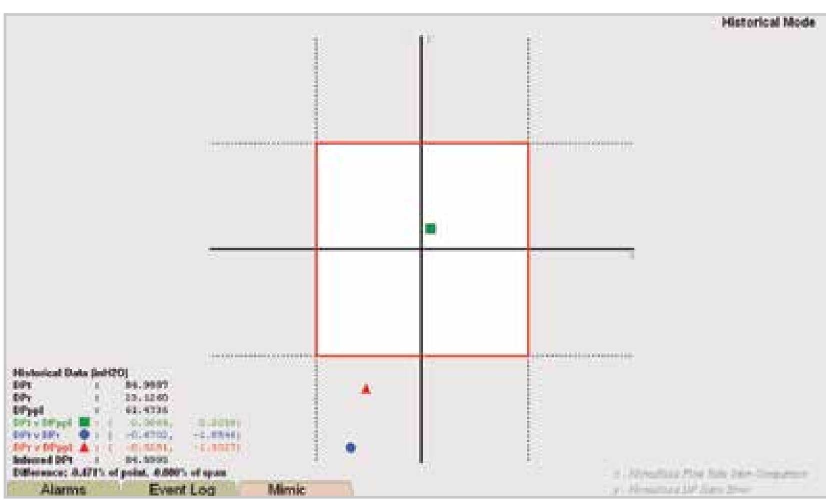


**Figure 14.** Inlet diameter too small 3.9”, (Nominal 4.0044”).

Next, the actual inlet diameter of 4.0044" was then set in the flow computer (and hence Prognosis) as 3.9", i.e. approximately the opposite of the above scenario. Figure 14 shows a screenshot of the Prognosis result. The DP integrity check showed the DP readings were correct with a registered "difference" of -0.47%, 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.

### A reversed (or "Backwards") 0.5 Beta Ratio Orifice Plate

For an approximate steady flow of 515 kg/min **Figure 15** shows a screenshot of the system result for a reversed plate. A reversed plate installation is a common problem throughout industry.

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 15** 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. For a given beta orifice plate a reversed (or 'backwards') plate, presents the flow a precise geometry change compared to a correctly installed plate. Hence, the system response is always the same for a given beta. The co-ordinates of this diagnostic plot are indicative of a 0.5β reversed orifice plate.

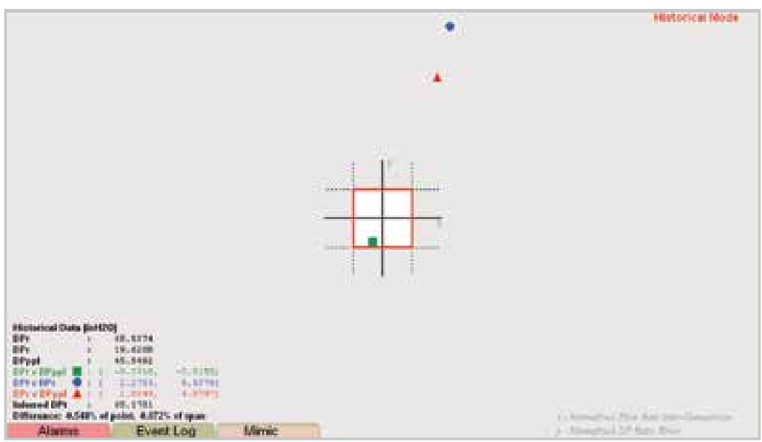


**Figure 15.** A 4", 0.5ß reversed orifice plate.

### A damaged orifice edge

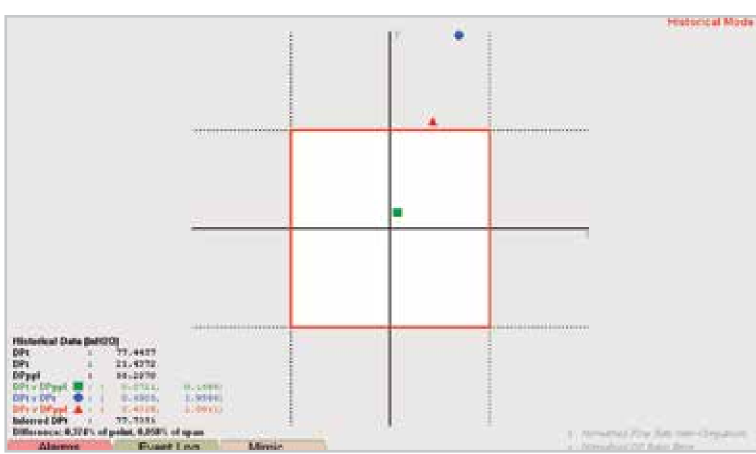


**Figure 16.** An orifice plate with a damaged edge.

**Figure 17** shows substantial damage done to an orifice plate. For an approximate steady flow of 500 kg/min, **Figure 16** 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 16 showed that the meter had no DP reading problem but a significant meter body problem.

**Figure 17.** Damaged orifice plate.

**Partial blockage of an orifice plate**

**Figure 18** shows a “half moon orifice plate”. This mimics an orifice plate with a partial blockage. CIATEQ installed this in the orifice meter with the system. The blockage was at top dead center.

**Figure 18.** 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 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 19** shows a screenshot of the system 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 19 showed that the meter has no DP reading problem but a significant meter body problem. All three diagnostic points are well outside the NDB.


**Figure 19.** A partial blockage of the orifice.

## CEESI gas flow orifice meter prognosis tests

The response of the system was tested to various orifice meter malfunctions. However, due to the wide number of possible meter malfunctions, the nature of the water flow tests facility, and time & budget restraints, there were some orifice meter potential malfunctions for which system was not tested.

Orifice meter malfunctions have been extensively tested during the initial development of these diagnostics techniques. In this section the response of these orifice meter diagnostics to three malfunctions initially not tested are shown. The data from these examples are presented here by excel created plots on the NDB (and not screenshots as in Section 3) as these tests were conducted prior to the development of the system.

### Contaminated orifice plate

Contaminates can deposit on plates (and meter runs) leading to orifice meter flow rate prediction errors. If an orifice plate is contaminated there are no traditional internal meter diagnostics to indicate the meter has a problem. Traditionally the meter operator must assume (i.e. hope) that the plate is clean.

Figure 20 shows a 4", 0.5β paddle orifice plate meter installed in an air blow down facility. The flow conditions were an air pressure of 15 Bar(a), a temperature of 303K, and a Reynolds number of 1.5e6. Figure 21 shows a sample diagnostic result when this meter was operating correctly. The system standard default uncertainty settings were used here, i.e. *x*=1%, *y*=2.5%, *z*=2.5%, *a*=3%, *b*=2.5%, *c*=4% & .

**Figure 22** shows a heavily contaminated 4", 0.5β orifice plate that was then tested at under these same flow conditions. This contaminated orifice meter flow rate prediction had a -4% bias.

Figure 20. Air blow down facility with a 4", 0.5ß paddle plate orifice meter installed with a 6D downstream pressure port for diagnostics.

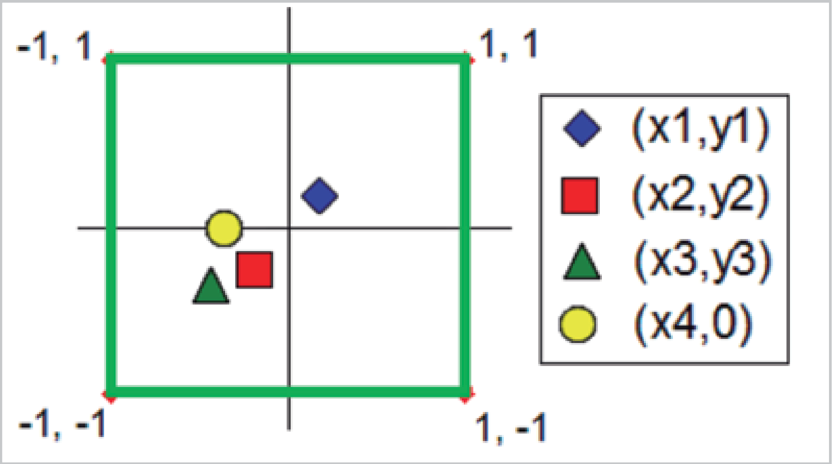


Figure 21. Air blow down facility 4", 0.5ß paddle plate orifice meter baseline diagnostic result.

**Figure 22.** Contaminated orifice plate.

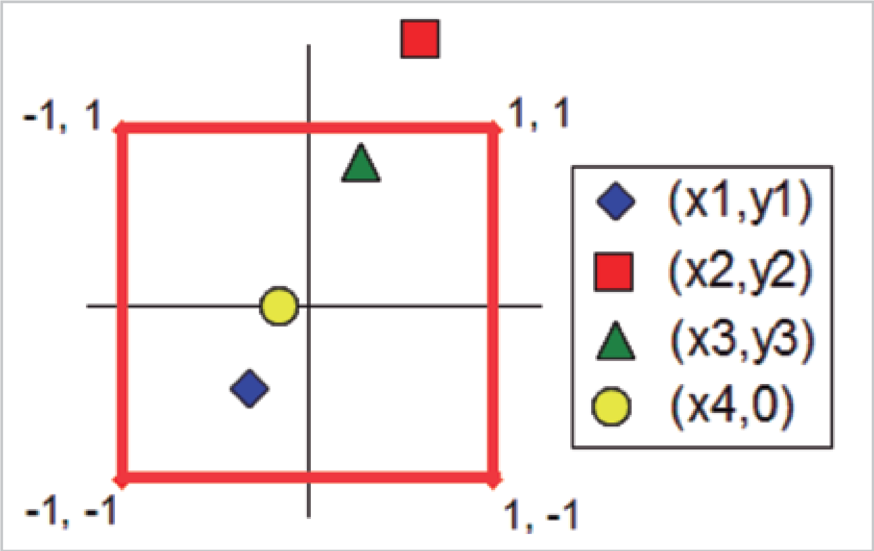


**Figure 23.** Contaminated orifice plate system response.

**Figure 23** shows the associated system response. One of the diagnostic points is outside the NDB correctly indicating the meter malfunction.

**Orifice plate meter installation effects**

DP Diagnostics installed a half moon orifice plate, or "HMOP", see **Figure 24** are blow down facility upstream of a 4", 0.5β meter. This would seriously disrupt the flow into a 4", 0.5 beta ratio orifice meter. Initial HMOP positions of 22D & 11D upstream was found to have no significant adverse effect on the meter and no corresponding diagnostic alarm[1]. The HMOP was then positioned extremely close to the orifice meter at 2D upstream. At a air pressure of 15 Bar(a), a temperature of 307K, and a Reynolds number of 1.2e6; this extreme flow disturbance into the meter induced a gas flow rate prediction bias of -5.5%. **Figure 25** shows the associated system response. All diagnostic points are outside the NDB, correctly indicating the meter malfunction.

**Figure 24.** HMOP created upstream flow disturbance.

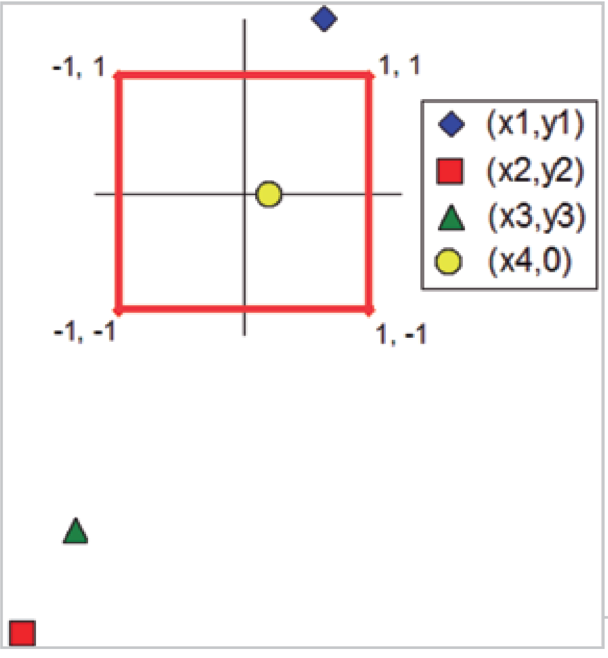


**Figure 25.** Disturbed flow diagnostic result.

**Wet gas flow**

Wet gas flow through an orifice meter causes the orifice meter to incorrectly predict the gas flow rate. If wet gas flows through an orifice plate, there are no traditional internal meter diagnostics to indicate that the meter is operating in error. Traditionally the meter operator must assume (i.e. hope) that the flow is not wet.

**Figure 26** shows a photograph of a 4", 0.62β orifice meter installed in the wet gas flow facility. DP Diagnostics received wet gas flow orifice meter data from system, **Figure 27** shows a still from a wet gas video of wet gas flow upstream of an orifice meter under test. **Figure 28** shows an orifice meter diagnostics systems (i.e. the 'Prognosis') response to a wet natural gas flow at pressure of 42.6 bar, a temperature of 305K, a gas density of 32 kg/m$^3$ and an actual gas flow rate of 3.3 kg/s. However, a light hydrocarbon liquid of density 731 kg/m$^3$ also flowed with the natural gas at a rate of 0.395 kg/s. This is a GVF of 98.9%. Approximately 1% of the total volume flow was liquid.

The 4", 0.62β orifice meter predicted the gas flow rate to be 3.43 kg/s, i.e. there was a positive gas flow rate bias (or an over-reading) of approximately 4%. Figure 28 shows the diagnostic result indicated that the orifice meter has a significant problem. This is the first orifice meter diagnostic system to show a flow rate prediction error when the flow is wet.

**Figure 26.** 4" Orifice meter with downstream pressure port at the CEESI wet gas flow facility.

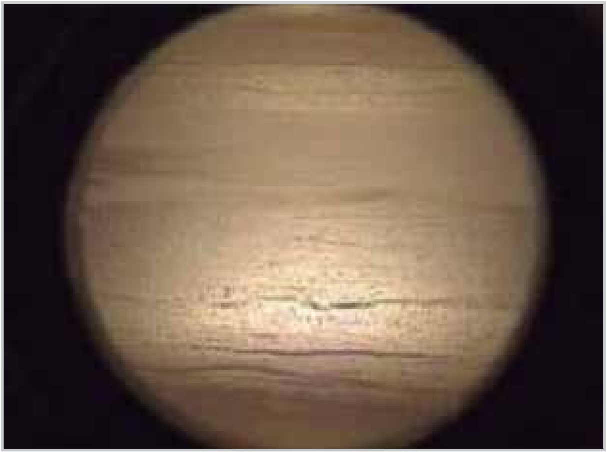

**Figure 27.** Photograph of wet gas flow.

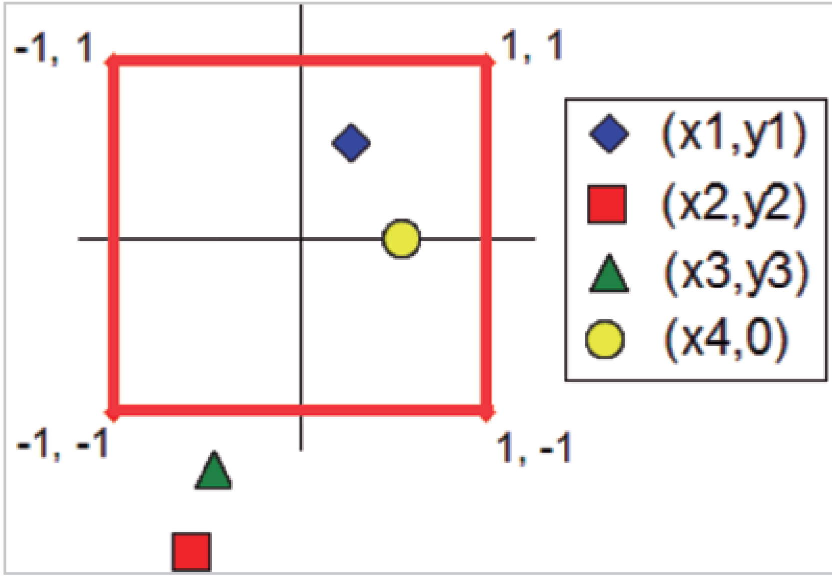


**Figure 28.** Wet gas orifice plate system response.

## Orifice meter diagnostics field trials

In 2012 field trialed the orifice meter diagnostic system was field trialed, on a 10” schedule 80 dual chamber orifice meter with a 0.4614β plate. The internal diameter was 9.75” and the orifice diameter was 4.50”. **Figure 28** shows a photograph of the orifice meter after the diagnostic system had been installed. This orifice meter was an in-service commercial gas transmission meter. Actual gas flow conditions are withheld.

**The system with a correctly operating orifice meter at the gas station**

After installation the base line of the diagnostic system, i.e. the response of system on the correctly operating meter. **Figure 30** shows a sample system screenshot from this baseline test. System is showing the Franklin orifice meter system to be fully serviceable. DP check (as a purple circle), indicating that the DP set was read correctly, i.e. the read and inferred traditional DP agreed to 0.76% (i.e. < ±1%) as required. The other three points indicate the meter body is operating correctly.

**Figure 29.** Dual chamber 10”orifice meter run with the system installed.

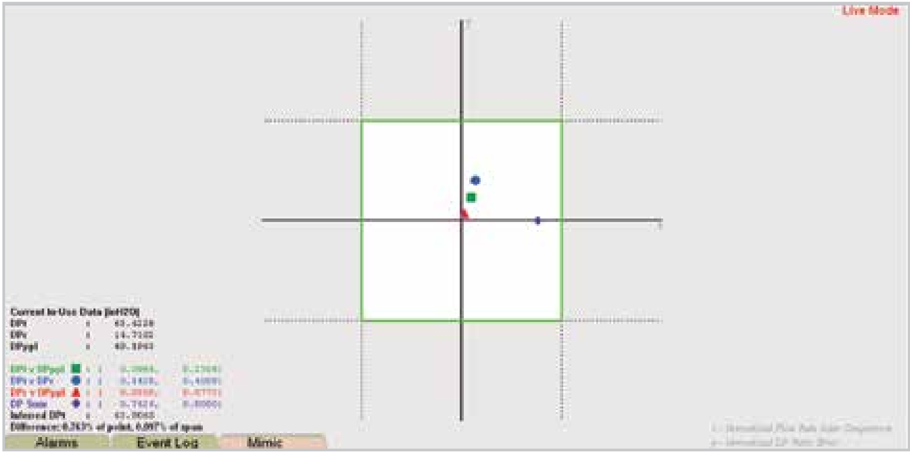


**Figure 30.** Dual chamber 10” orifice meter run system baseline result.

Once the system correctly showed that the well maintained orifice meter was fully serviceable, the staff deliberately induced meter malfunction issues on the test meter.

### Orifice meter at with a backwards installed orifice plate

The first deliberate malfunction was a backwards installed orifice plate. The system result is shown as a screenshot in **Figure 31**. The system shows that the orifice meter has a problem. The DP check shows the DPs are read correctly. The problem is with the meter body. Note the similarity in the pattern between the 4”, 0.5β water flow reversed plate test result (Figure 15), and the 10”, 0.46β natural gas flow reversed plate test result, (Figure 31). The slight difference is accounted for by the sight difference in beta and the fact that actual live monitoring (from where the screenshots were taken) sees the natural standard deviation of the DPs, being read meaning that the system points vary slightly around average points screenshot to screenshot. This system pattern (and approximate co-ordinates) is a tell tale sign off a reversed plate installation.

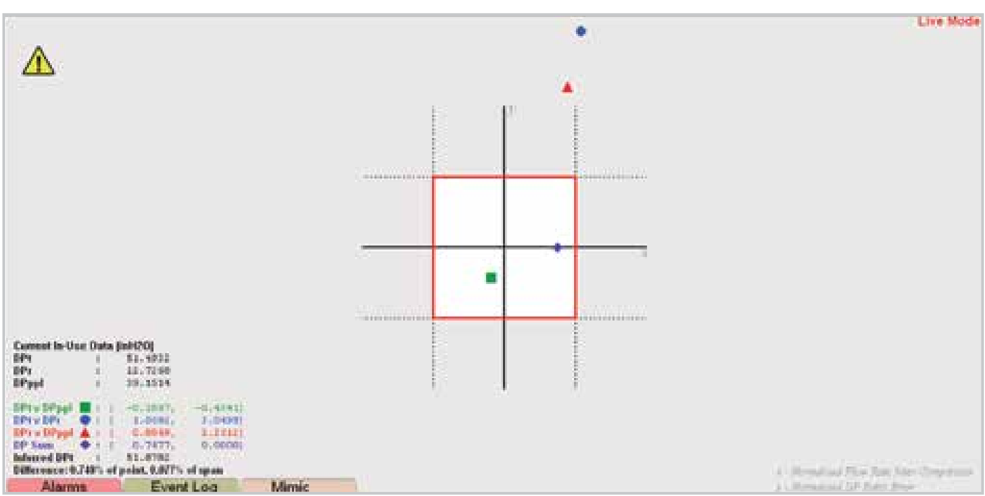


**Figure 31.** Dual chamber orifice 10” meter backwards plate system result.

**Orifice meter with a Leaking Five Way Manifold**

After the staff had re-installed the plate correctly and the system result was again showing the metering system was fully serviceable the traditional DP transmitters 5-way manifold equalization valve was cracked open to induce a leak between the high and low pressure ports. This induces an error in the read traditional DP.

**Figure 32** shows the corresponding the system response. The DP check indicates that the read DP set cannot be correct. That is, the system is correctly showing a metering system malfunction, and that its source is in the DP transmitters instrumentation. Furthermore, the diagnostic point that remains inside the NDB is the single point that does not utilize the traditional DP. Therefore, the system has shown the metering system has a problem, is with the DP measurement; it is the traditional DP measurement that is incorrect, while the recovered and PPL DP readings are correct. In this case the correct DP can be inferred by summing the correct recovered and PPL DP readings (see equation 1), and the actual flow rate can be predicted. Alternatively, the correct recovered and PPL DP readings can predict the gas flow rate independently (see equations 3 & 4). Hence, in this case although the system indicates a metering system malfunction, it also tells the operator the correct gas flow rate and the level of the gas flow rate error, until maintenance can be arranged to fix the traditional DP transmitters reading.

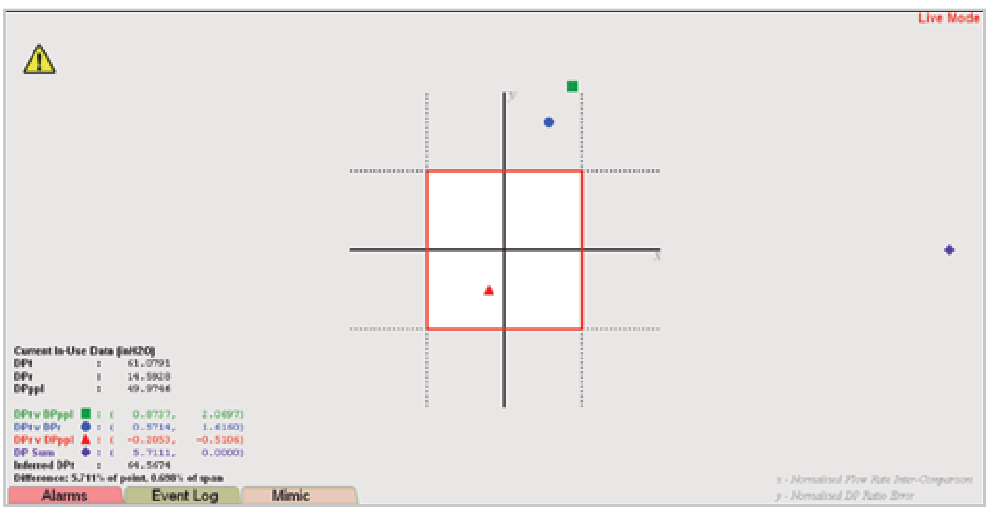


Figure 32. Orifice 10” meter with Incorrect Traditional DP Reading.

**Orifice meter with a blocked upstream impulse line**

After the 5-way manifold equalization valve was re-sealed and the system points returned inside the NDB the inlet pressure impulse line was shut with a valve to simulate an impulse line blockage. This traps the inlet pressure at the value at the moment of blockage.

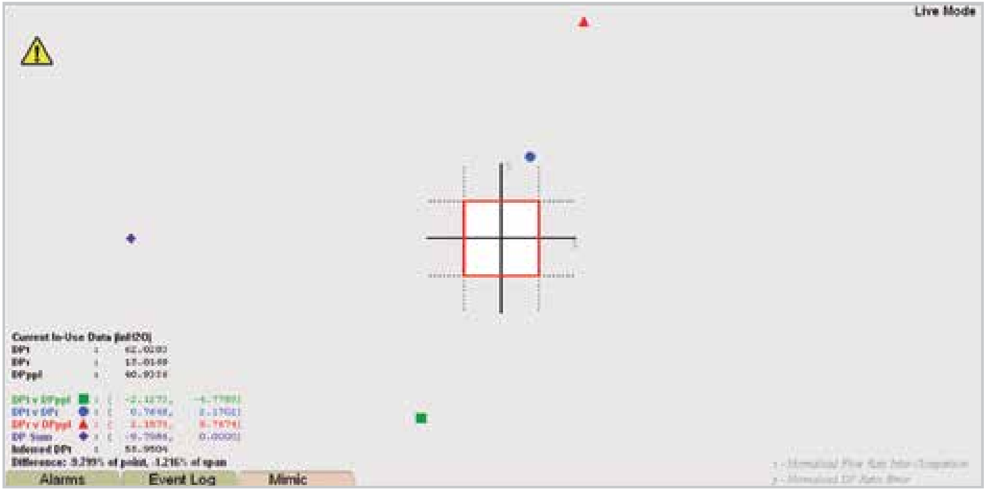


**Figure 33.** Orifice 10” meter with blocked / plugged inlet impulse line.

Even very small pipeline pressure variations (of typical magnitude in production and transmission meter installations) will then cause extreme errors in the DPs read via that blocked impulse line, as the other impulse line pressures are free to move with the flow pressure while the blocked impulse line pressure is not. As all the diagnostic points in system are from pairs of DPs, and any pair of DPs must use at least one DP affected by the blockage, all system points are adversely affected. **Figure 33** shows a screenshot of the resulting system response. In practice the diagnostic response fluctuates with the very small line pressure fluctuations and the response is therefore rather unsteady. The unsteadiness of the diagnostics in itself hints at a possible source of the problem.

**Orifice meter with incorrect keypad entered orifice diameter**

The actual orifice bore in use was 4.50”. **Figures 34** represents the orifice meters system response for the orifice diameter being keypad entered too low (4.25”). System shows that the meter has a problem. The DP check indicates that the DP set read is trustworthy. System is therefore correctly stating that the meter body has a problem.

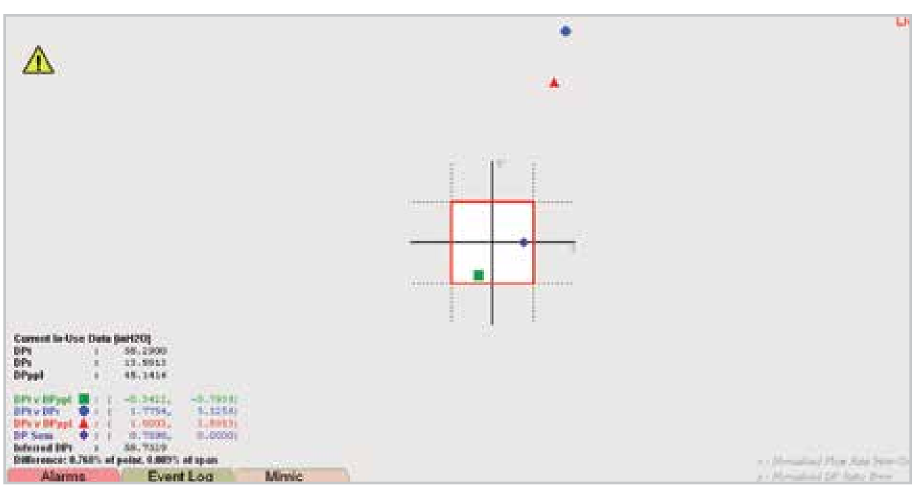


**Figure 34.** Orifice meter 10”with keypad entry error on orifice diameter.

**Orifice meter at with incorrect keypad entered meter diameter**

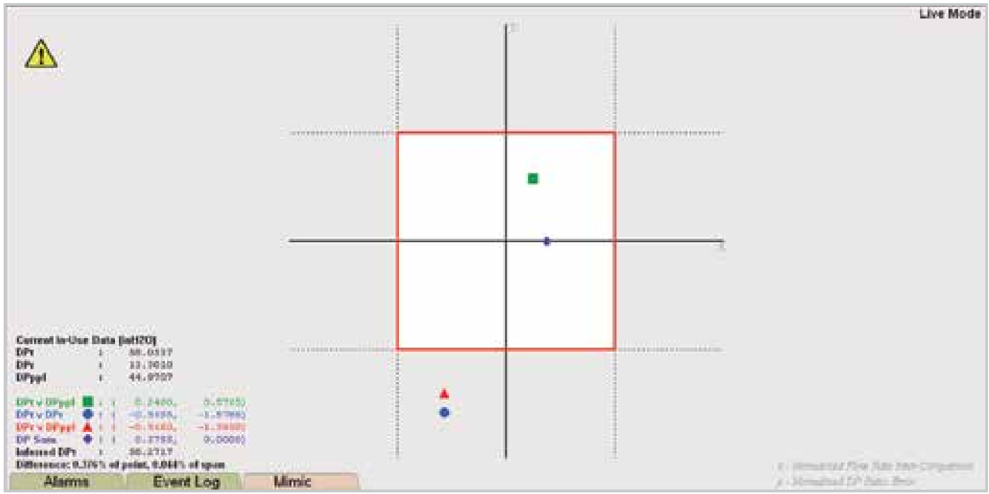


**Figure 35.** Orifice meter 10”with keypad entry error on orifice diameter.

The actual orifice bore in use was 9.75” (i.e. 10” sch 80S). **Figures 35** represents the orifice meters system response for the inlet diameter being keypad entered too low high (9.562” – i.e. schedule 80 instead of the correct schedule 80). Prognosis shows that the meter has a problem. The DP check indicates that the DP set read is trustworthy. Prognosis is therefore correctly stating that the meter body has a problem.

## Conclusions

Have developed 4 comprehensive diagnostic system for orifice (and other DP) meters. This system has been repeatedly tested both by DPD & ST, and also by third parties, in various laboratories, field trials and in industrial service.

The water flow tests on a 4”, 0.5β orifice meter, gas flow tests on various 4” orifice meters, the field tests on a 10”, 0.46β orifice meter, and a multiple of other tests, have shown that the diagnostic principles on which the system 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.

The tests were witnessed by members of the Mexican Hydrocarbon National Commission (CNH, short in Spanish). Presently, in order to audit orifice plate metering systems according to the regulation set by CNH, it is necessary to stop operation of the metering system. However, due to the capability of the system to monitor metering systems on line (in operation), it is now technically possible to have a Condition Based Maintenance (‘CBM’) policy instead of a Schedule Based Maintenance policy. This makes very attractive and practical for compliance.

The system has the ability to show meter malfunctions occurring in real time. In the likely event the diagnostics are not continuously or regularly monitored, they allow historical archived data to pin point when an event occurred. Prognosis can show problems developing (such as contamination depositing over time, orifice plate edge wear over time, wet gas liquid loading increasing or reducing over time), by trending the response over time. This can protect the operator against flow rate mis-measurement and can reduce needless scheduled maintenance. Furthermore, when Prognosis indicates maintenance is indeed requiring the technician, does not go to the meter “blind”. The system 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 the system will state which instrument has redundancy to cover for that failure. If the problem is with the meter body, the system 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.

The current software not only shows if a meter has malfunctioned, a short list of possible sources of that malfunction is offered. This short list comes from pattern recognition. The reader may note from the examples in this paper that different problems can cause different patterns on the NDB plot. Whereas a particular pattern may not be unique to one malfunction, it can exclude certain malfunctions that could not cause that particular pattern. This can significantly reduce the maintenance time required to return the meter to service.

The system 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.

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