

# Cone DP Flow Meters

## – Comments & Lessons from 15 Years of Calibration Experience

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### Abstract

Cone DP meters are popular generic differential pressure (DP) meters that are used in many industries. There are as yet no cone meter standards documents. Each cone meter is individually calibrated to characterize the meters performance. CEESI has calibrated many cone meters over the last 15 years. This paper shows some massed data sets on cone meter performance and reviews the likelihood of a cone meters performance being predicted without a dedicated calibration. The paper then reviews in detail the calibration data of a large 48", 0.616 beta ratio cone meter, and introduces a new DP Diagnostics DP meter diagnostic system that was included in the CEESI calibration procedure of this 48" cone meter.

### Introduction

With no cone meter standards it is presently good practice to calibrate each cone meter across the applications full Reynolds number range to characterize the meters performance. Industry would like to be able to predict the cone meters performance without calibration being necessary. With 15 years of cone meter calibration experience, CEESI has massed and blinded cone meter calibration data sets, from four different cone meter manufacturers, to investigate the possibility of predicting a cone meters performance without calibration being necessary. A rare 48" cone meter data set is then discussed in relation to the earlier findings. This 48" cone meter was calibrated at CEESI with a new DP Diagnostics diagnostic system installed. The results and lessons learned are discussed.

### A Massed Cone Meter Data Set

This CEESI blinded data set includes meters manufactured by four companies. All cone meters considered were the classical design of the DP read between the upstream port and the low pressure port at the back face of the cone. This data set is a relatively small part of the over-all data gathered by CEESI over 15 years. However, it is seen as representative sample of that overall data set. The range of the data used in this research is given in Table 1. Test fluids were air, water or natural gas.

Every one of the 141 cone meter calibration results considered, without exception, could be individually data fitted such that the discharge coefficient ( $C_d$ ) vs.

Reynolds number relationship would predict the discharge coefficient to < 1%, and in the vast majority of cases < 0.5%.

$1''(25.4 \text{ mm}) \leq \text{Nominal Inlet Diameter} \leq 16''(406.4\text{mm})$
$0.45 \leq \beta \leq 0.85$
$1.0 \leq \text{Pressure (Bar)} \leq 140.0$
$0.3 \leq \text{Velocity (m/s)} \leq 30$
$4.98\text{e-}3 \leq \text{DP (Bar)} \leq 2.50$

Table 1. Data Set Range from 141 generic cone meters.

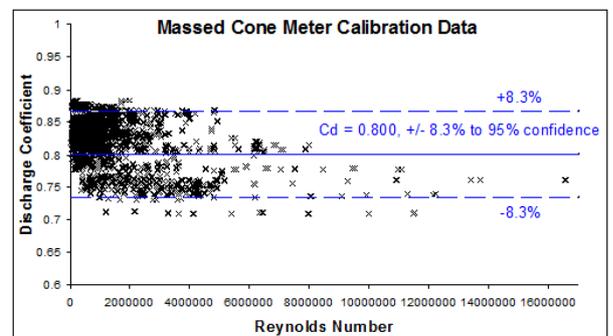


Fig 1. All 141 Cone Meter Calibration Data Sets.

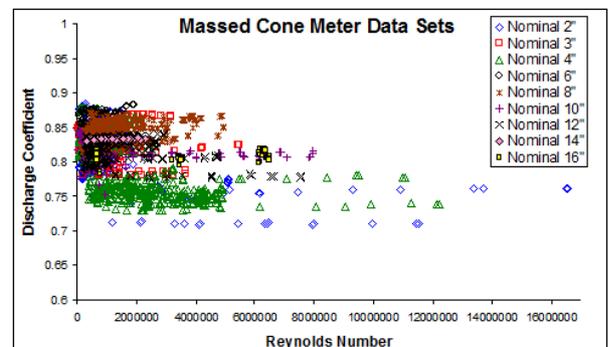


Fig 2. All Cone Meter Data Sets, Separated Diameters.

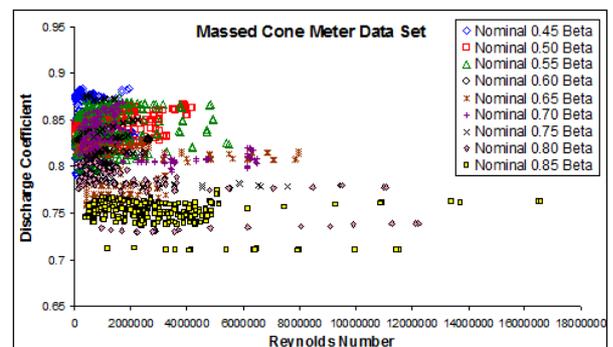


Fig 3. All Cone Meter Data Sets, Separated Beta Ratios.

Figure 1 shows all 141 cone meter calibration data sets as one massed data set. It was found that a constant discharge coefficient ( $C_d$ ) of 0.800 fitted all the data to 8.3% to 95% confidence. The reference meters were sonic nozzles, with uncertainty ratings of 0.3%. It was therefore found that it is not possible to use one set value of discharge coefficient for all cone meters and be guaranteed a flow rate prediction uncertainty of < 8%.

A properly calibrated cone meter can predict the flow rate to < 1%. An un-calibrated cone meter can only predict the flow rate to 8.3%. Therefore, all cone meters should be individually calibrated across the full Reynolds number range of the application.

In an attempt to reduce the un-calibrated cone meter flow rate prediction uncertainty meter size (i.e. inlet diameter) and beta ratio groups were isolated, as shown in Figures 2 & 3 respectively. Figure 2 shows that no inlet diameter / meter size relationship with discharge coefficient was found. Figure 3 shows that no clear and obvious beta ratio relationship with discharge coefficient was found. Figure 3 hints that there may be some beta ratio effect, with higher beta ratio meters tending to have a smaller discharge coefficient. However, there is a lot of scatter between nominally similar cone meters and it would be difficult to make any quantitative statements on any such phenomenon. Therefore, at the present time, it does not look like there is any possibility of significantly reducing the un-calibrated cone meter's discharge coefficient prediction uncertainty to < 8.3% by accounting for any possible diameter or beta ratio effect.

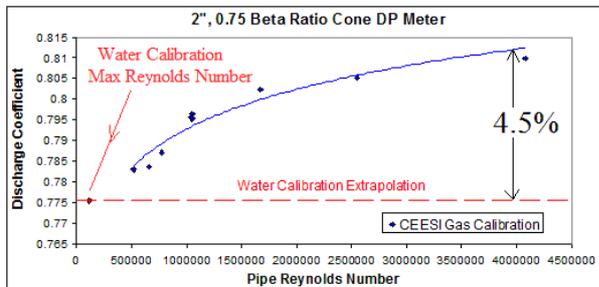


Fig 4. Cone Meter Data Across a Reynolds No. Range.

At the present time, individual calibration of a cone meter is the only way to assure the cone meter has a low flow rate prediction uncertainty. Furthermore, it is essential that the cone meter be calibrated across the applications full Reynolds number range. Figure 4 shows sample data from a 2", 0.75 beta ratio cone meter calibrated in a manufacturers water flow facility (at a low Reynolds number range) and then calibrated with gas at CEESI across the applications significantly higher actual Reynolds number range. It can be seen that the water calibration extrapolates to a false discharge coefficient therefore producing a flow rate prediction negative bias.

A cone meters flow rate prediction uncertainty statement is only valid across the Reynolds number range of the calibration. Extrapolating cone meter calibration data can and does lead to flow rate prediction gross biases.

## **48", 0.616 Beta Ratio Cone Meter**

CEESI calibrated a 48", sch ST, 0.616 beta ratio cone meter in the CEESI air blow down facility. The reference meter was a sonic nozzle with 0.3% uncertainty. Figures 5 & 5a show the installed cone meter. Figure 5 shows a pressure transmitter and four DP transmitters. The pressure transmitter read the inlet pressure. The traditional DP was read with a pair (i.e. a stack) of two DP transmitters. The other two DP transmitters were used to calibrate the DP meter diagnostic system 'Prognosis'. Figure 5a shows that a pressure tap approximately 6D downstream of the cone meter was available.



Fig 5. 48", 0.616 Beta Ratio Cone Meter



Fig 5a. Pressure Tap 6D Downstream of Cone Meter.

This 48" cone meters calibration result will now be compared against the massed data set for smaller cone meters. It will also be used to show the DP Diagnostics / Swinton Technology DP meter diagnostics system 'Prognosis' in operation. In order to do this it is first necessary to describe the diagnostic system.

The generic DP meter diagnostic system was first described by Steven in 2008 [1] & 2009 [2]. This diagnostic system was described in some detail for the particular case of cone meters by Steven in 2009 [3].

## Cone Meter Diagnostic System

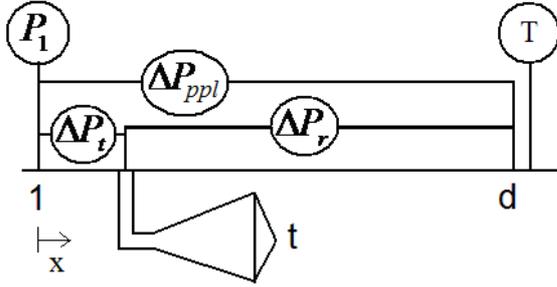


Fig 6. Cone meter with instrumentation sketch.

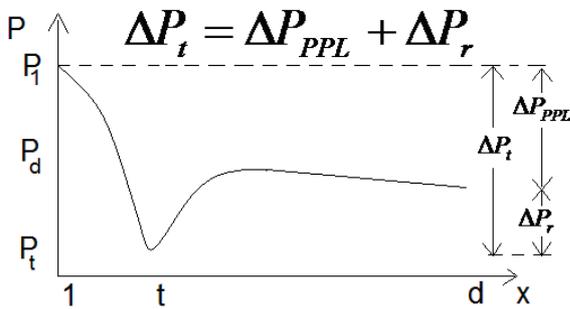


Fig 7. Simplified pressure fluctuation.

Figures 6 & 7 show sketch of a cone meter with instrumentation, and a (simplified) pressure fluctuation through the meter body. Traditional cone meters read the inlet pressure ( $P_1$ ) from a pressure port (1) directly upstream of the cone, and the differential pressure ( $\Delta P_t$ ) between the inlet pressure port and a pressure port positioned at the back face of the cone (t). The temperature (T) is also usually measured downstream of the meter. Note that the cone meter in Figure 6 (and Figure 5a) has a third pressure tap (d) further downstream of the cone. This allows the measurement of two extra DP's. That is, the differential pressure between the downstream (d) and the low (t) pressure taps (or "recovered" DP,  $\Delta P_r$ ) and the differential pressure between the inlet (1) and the downstream (d) pressure taps (i.e. the permanent pressure loss,  $\Delta P_{PPL}$ , sometimes called the "PPL" or "total head loss") could be read.

Adding the recovered DP to the PPL must give the traditional differential pressure (equation 1).

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

Each of these three DP's can be used to independently predict the flow rate. Equations 2 to 4 show the three flow rate calculations for these three DPs. Note that  $m_t$ ,  $m_r$  &  $m_{PPL}$  are the mass flow rate predictions of the actual flow when using the traditional, recovered and PPL DP's respectively. The terms E, A &  $A_t$  are constant geometry terms and  $\rho$  is the fluid density.  $\epsilon$  is the

$$\text{Traditional Equation: } m_t = EA_t \epsilon C_d \sqrt{2\rho \Delta P_t} \quad \text{-- (2)}$$

uncertainty  $\pm x\%$

$$\text{Expansion Equation: } m_r = EA_t K_r \sqrt{2\rho \Delta P_r} \quad \text{-- (3)}$$

uncertainty  $\pm y\%$

$$\text{PPL Equation: } m_{PPL} = AK_{PPL} \sqrt{2\rho \Delta P_{PPL}} \quad \text{-- (4)}$$

uncertainty  $\pm z\%$

expansion factor that accounts for any gas density variation through the meter. (For liquids  $\epsilon = 1$ .) The terms  $C_d$ ,  $K_r$  &  $K_{PPL}$  represent the flow coefficients required by each meter calculation. They are the discharge, expansion and PPL coefficients respectively. These flow coefficients can either be set to a constant value or, for more precision, they can be related to the flows Reynolds number. All three flow coefficients can be found by the same cone meter calibration.

It has now been shown that every cone meter is in effect three flow meters in series. As there are three flow rate predictions for the same flow through the same meter run there is the potential to compare these flow rate predictions and hence have a diagnostic system.

Naturally, all three flow rate predictions have individual uncertainty ratings (say  $x\%$ ,  $y\%$  &  $z\%$  as shown in equations 2 through 4). Hence, even if a cone meter is operating correctly, no two flow predictions would match *precisely*. However, a correctly operating cone meter will produce flow predictions that are very close to each other. An operator can therefore choose an acceptable maximum difference between any two of these flow rate predictions.

Let us denote the **actual** difference between the traditional & PPL meter flow predictions as " $\psi\%$ ". Let us denote the maximum **allowable** difference between the traditional & PPL meters flow predictions as " $\phi\%$ ", which is usually taken as the rms of the two meter flow rate uncertainties. If the actual difference is less than the allowable difference (i.e.  $|\psi\% / \phi\%| \leq 1$ ) no meter malfunction is found. If the actual difference is more than the allowable difference (i.e.  $|\psi\% / \phi\%| > 1$ ) a meter malfunction has been found.

Let us denote the **actual** difference between the traditional & expansion meter flow predictions as " $\lambda\%$ ". Let us denote the maximum **allowable** difference between the traditional & expansion meters flow predictions as " $\xi\%$ ", which is usually taken as the rms of the two meter flow rate uncertainties. If the actual difference is less than the allowable difference (i.e.  $|\lambda\% / \xi\%| \leq 1$ ) no meter malfunction is found. If the

actual difference is more than the allowable difference (i.e.  $|\lambda\%/\xi\%| > 1$ ) a meter malfunction has been found.

Let us denote the **actual** difference between the PPL & expansion meter flow predictions as “ $\chi\%$ ”. Let us denote the maximum **allowable** difference between the traditional & expansion meters flow predictions as “ $\nu\%$ ”, which is usually taken as the rms of the two meter flow rate uncertainties. If the actual difference is less than the allowable difference (i.e.  $|\chi\%/\nu\%| \leq 1$ ) no meter malfunction is found. If the actual difference is more than the allowable difference (i.e.  $|\chi\%/\nu\%| > 1$ ) a meter malfunction has been found.

It is possible to take a different diagnostic approach. The **Pressure Loss Ratio** (or “PLR”) is the ratio of the PPL to the traditional DPs. The **Pressure Recovery Ratio** (or “PRR”) is the ratio of the recovered to traditional DPs. The **Recovery to Permanent Pressure Loss DP Ratio** (or “RPR”) is the ratio of the recovered to PPL DPs. For a correctly operating cone meter all three DP ratios are a set constant value (with an associated uncertainty), or can be expressed as a function of Reynolds number for lower uncertainty. These DP ratio values can be found by the same calibration as finds the flow coefficients discussed above. Note the three DP ratios are inter-related. Rewriting equation 1 gives equation 5. The relationship of RPR to PLR & PRR is shown as equation 6. Hence, if one DP ratio is known then all three are known.

$$\frac{\Delta P_r}{\Delta P_t} + \frac{\Delta P_{PPL}}{\Delta P_t} = PLR + PRR = 1 \quad -- (5)$$

$$RPR = \frac{PRR}{PLR} \quad -- (6)$$

All three DP ratios produced by a correctly calibrated and correctly operating cone meter system are known. An operator can assign allowable uncertainties to these three DP ratio predictions:

PPL to Traditional DP ratio (PLR):

$$\left( \Delta P_{PPL} / \Delta P_t \right)_{cal}, \quad \text{uncertainty} \pm a\%$$

Recovered to Traditional DP ratio (PRR):

$$\left( \Delta P_r / \Delta P_t \right)_{cal}, \quad \text{uncertainty} \pm b\%$$

Recovered to PPL DP ratio (RPR):

$$\left( \Delta P_r / \Delta P_{PPL} \right)_{cal}, \quad \text{uncertainty} \pm c\%$$

Here is another method of using the three DP’s to check a cone meters health. Actual DP ratios found in service can be compared to the known correct operational DP ratio values.

Let us denote the **actual** difference between the PLR as found and the correct operation PLR value as  $\alpha\%$ . Let us denote the maximum allowable difference between these values as  $a\%$ . If the actual difference is less than the allowable difference (i.e.  $|\alpha\%/a\%| \leq 1$ ) no meter malfunction is found. If the actual difference is more than the allowable difference (i.e.  $|\alpha\%/a\%| > 1$ ) a meter malfunction has been found.

Let us denote the **actual** difference between the PRR as found and the correct operation PRR value as  $\gamma\%$ . Let us denote the maximum allowable difference between these values as  $b\%$ . If the actual difference is less than the allowable difference (i.e.  $|\gamma\%/b\%| \leq 1$ ) no meter malfunction is found. If the actual difference is more than the allowable difference (i.e.  $|\gamma\%/b\%| > 1$ ) a meter malfunction has been found.

Let us denote the **actual** difference between the RPR as found and the correct operation RPR value as  $\eta\%$ . Let us denote the maximum allowable difference between these values as  $c\%$ . If the actual difference is less than the allowable difference (i.e.  $|\eta\%/c\%| \leq 1$ ) no meter malfunction is found. If the actual difference is more than the allowable difference (i.e.  $|\eta\%/c\%| > 1$ ) a meter malfunction has been found.

Equation 1 holds true for all cone meters. The three DPs can be checked against equation 1. Any result that suggests that it does not hold true is a statement by the diagnostic system that there is an erroneous DP reading coming from the instrumentation. The traditional DP ( $\Delta P_t$ ) can be inferred by summing the read recovery DP ( $\Delta P_r$ ) and permanent pressure loss ( $\Delta P_{PPL}$ ). This inferred traditional DP ( $\Delta P_{t,inf}$ ) can be compared to the directly read traditional DP ( $\Delta P_{t,read}$ ). Due to the uncertainties of the three DP transmitters, even for correctly read DPs, the directly read & inferred traditional DPs can be slightly different. The percentage difference ( $\delta\%$ ) can be calculated as seen in equation 7.

$$\delta\% = \{ (\Delta P_{t,inf} - \Delta P_{t,read}) / \Delta P_{t,read} \} * 100\% \quad -- (7)$$

Assigning a maximum allowable percentage difference ( $\theta\%$ ) between the directly read and inferred traditional DP values produces a DP reading integrity check. If the actual difference is less than the allowable difference (i.e.  $|\delta\%/\theta\%| \leq 1$ ) no DP reading error is found. If the actual difference is more than the allowable difference (i.e.  $|\delta\%/\theta\%| > 1$ ) a DP reading error has been found.

Table 2 shows the seven situations where these diagnostics will produce a meter malfunction warning.

DP Pair	No Alarm	ALARM
$\Delta P_t$ & $\Delta P_{PPL}$	$ \psi\% / \phi\%  \leq 1$	$ \psi\% / \phi\%  > 1$
$\Delta P_t$ & $\Delta P_r$	$ \lambda\% / \xi\%  \leq 1$	$ \lambda\% / \xi\%  > 1$
$\Delta P_{PPL}$ & $\Delta P_r$	$ \chi\% / \nu\%  \leq 1$	$ \chi\% / \nu\%  > 1$
$\Delta P_t$ & $\Delta P_{PPL}$	$ \alpha\% / a\%  \leq 1$	$ \alpha\% / a\%  > 1$
$\Delta P_t$ & $\Delta P_r$	$ \gamma\% / b\%  \leq 1$	$ \gamma\% / b\%  > 1$
$\Delta P_{PPL}$ & $\Delta P_r$	$ \eta\% / c\%  \leq 1$	$ \eta\% / c\%  > 1$
$\Delta P_{PPL}$ & $\Delta P_t$	$ \delta\% / \theta\%  \leq 1$	$ \delta\% / \theta\%  > 1$

Table 2. Possible diagnostic results.

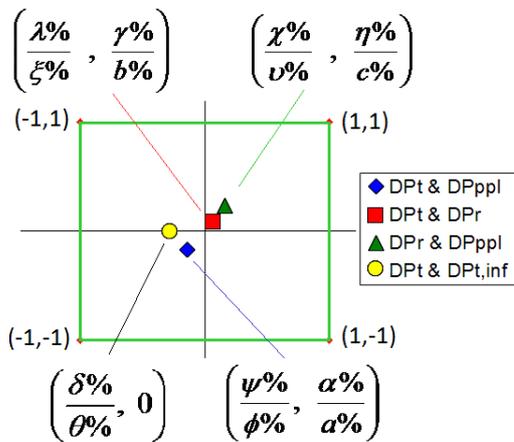


Fig 8. A diagnostic result plotted on a diagnostic box.

For practical use by typical operator personnel (who do not need know the details of the diagnostic method), a plot of these diagnostic results on a graph is simple and effective. Such a plot can be continually updated in real time on a control room screen or the data can archived for later analysis.

Figure 8 shows such a plot. A normalized diagnostic box (or 'NDB') can be superimposed on a graph with corner co-ordinates: (1,1), (1,-1), (-1,-1) & (-1,1). On such a graph four meter diagnostic points can be plotted.

These are  $(\psi\% / \phi\%, \alpha\% / a\%)$  for the traditional & PPL DP pair,  $(\lambda\% / \xi\%, \gamma\% / b\%)$  for the traditional & recovered DP pair,  $(\chi\% / \nu\%, \eta\% / c\%)$  for the PPL & recovered DP pair and  $(\delta\% / \theta\%, 0\%)$  for the DP integrity check. If all points are within or on the NDB then no metering problem is found and the traditional meters flow rate prediction can be trusted. If one or more of the four points falls outside the NDB then the meter is *not* operating correctly and the meters traditional (or any) flow rate prediction cannot be trusted. The further from

the NDB the points are, the more potential for significant meter error there is.

## 48", Sch ST, 0.616 Beta Ratio Cone Meter $C_d$ Calibration Results

The calibration result for the 48", 0.616 beta ratio cone meter is shown in Figure 9. A constant discharge coefficient of 0.7793 fits the data to 0.5% uncertainty. Also shown in Figure 9 are the above fitted discharge coefficient of 0.800 with the 8.3% uncertainty and the manufacturers sizing program estimation for that meters discharge coefficient of 0.840.

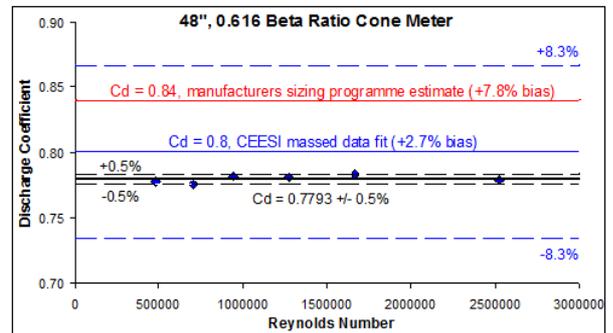


Fig 9. 48", 0.616 Beta Ratio Cone Meter Calibration.

It is shown that not calibrating the cone meter, and using the discharge coefficient of 0.800 instead, would produce a positive bias in the flow rate prediction of 2.7%. It is shown that not calibrating the cone meter, and using the discharge coefficient predicted by the manufacturers sizing program would produce a positive bias in the flow rate prediction of 7.8%. Both these results are of course within the 8.3% uncertainty of the discharge coefficient 0.800 data fit. However, these examples highlight the difficulty in predicting a cone meters performance without calibrating the meter.

It is possible to fit the discharge coefficient to Reynolds number to a lower uncertainty. Figure 10 shows a linear fit giving the discharge coefficient as 0.4% uncertainty.

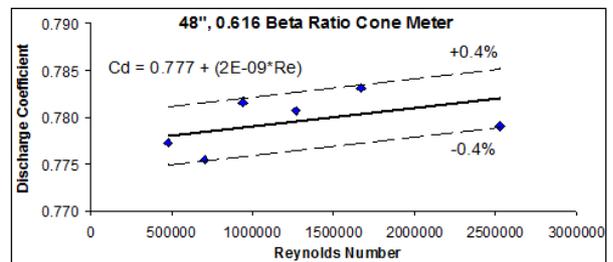


Fig 10. 48", 0.616 Beta Ratio Cone Meter Linear Fit.

## 48", Sch ST, 0.616 Beta Ratio Cone Meter Diagnostic Calibration Results

The full DP meter diagnostic calibration results are shown in Figures 11 (for the flow coefficients) and Figures 12 (for the DP ratio values). It is shown that all

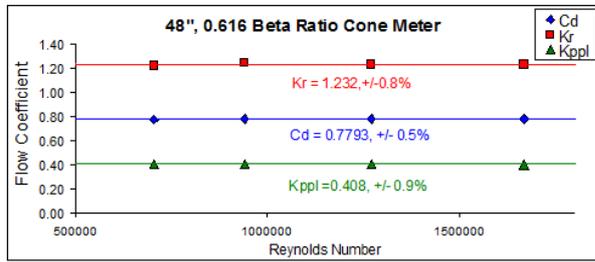


Fig 11. Prognosis Flow Coefficient Calibration Results.

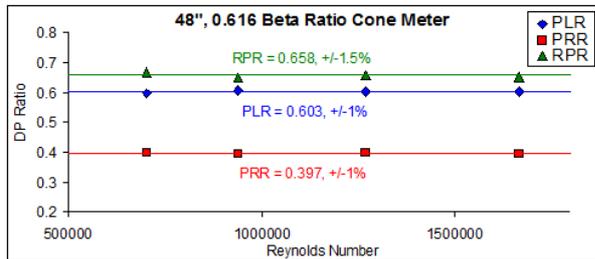


Fig 12. Prognosis DP Ratio Value Calibration Results.

six diagnostic parameters can be stated as constant values to stated uncertainties. Hence, as of this CEESI calibration the meter is fully diagnostic ready. Note that as it is necessary to calibrate each individual cone meter to find the discharge coefficient it is little more effort, time or expense to calibrate the cone meter to make it diagnostic ready. Figure 13 shows a sample diagnostic result using one of the calibration results. In itself this result is trivial as the data used is the same data used to calibrate the meters diagnostic system. The interesting non-trivial results are from the diagnostic response if the cone meter is given a problem.

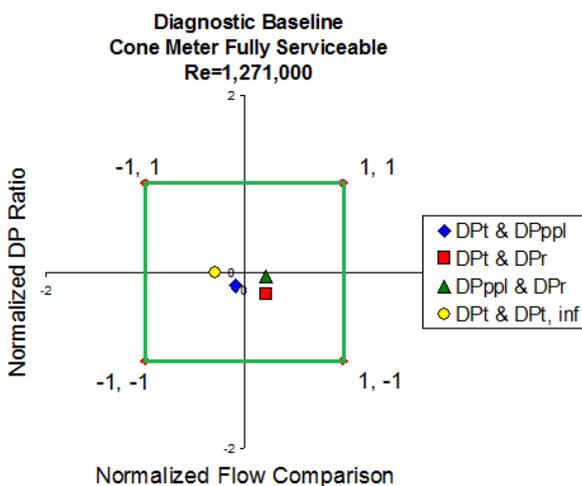


Fig 13. Prognosis Result From CEESI Calibration Data.

## Diagnostic System Worked Examples

As with all flow meters there are various problems a cone meter can face in service. Although no deliberate meter malfunctions were tested at CEESI we can still show the diagnostic system virtual problems on the calibration data. Such virtual problems include incorrect inlet or cone diameter keypad entry to the flow computer, incorrect discharge coefficient keypad entry to the flow computer or DP reading errors. The following examples use the calibration data point shown in Figure 13. Note that Figure 13 is the correct diagnostic result when the meter is fully serviceable.

### Incorrect Entry of Inlet Diameter

The 48" cone 0.616 $\beta$  meter has an inlet diameter of 47.257" / 1.2003m. By way of example, when randomly selecting a baseline / calibration result (i.e.  $Re = 1,270,682$ ), input the inlet diameter as not 47.257" but as 47.527" (i.e. mimicking a typing error by swapping two numbers). This too large a cone meter inlet diameter induces a traditional flow rate equation prediction error of approximately +3.3%<sup>1</sup>. However, the diagnostics are sensitive to the issue. Figure 14a shows the result. Note that the correct diameter gave the diagnostic result shown in Figure 13.

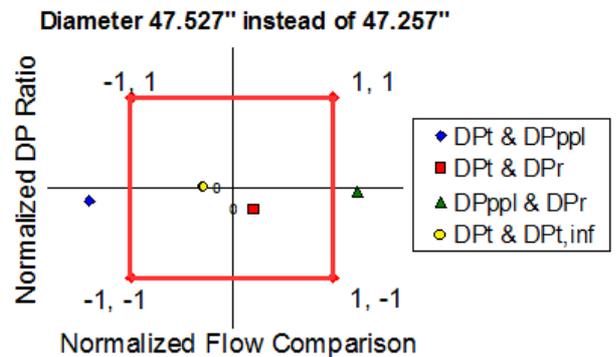


Fig 14a. Inlet Diameter Entered Too Large

By way of example, change this inlet diameter input so as it is not the correct 47.527" but as an incorrect 47". That is, the decimal place digits have been ignored or forgotten. This too small a cone meter inlet diameter

<sup>1</sup> The cone meter is relatively sensitive to inlet diameter errors compared to traditional DP meter designs such as orifice and cone meters (which are notably rather insensitive to this issue). This is due to the fact that unlike traditional DP meters where the inlet and throat diameters are stated, and the inlet and throat areas are then independently calculated, with a cone meter the inlet and cone diameter or beta ratio are stated. Hence, unlike Venturi & orifice meters, the calculation of the cone meter throat area is dependent on the inlet diameter. This causes a cone meter inlet diameter error to affect the throat area calculation making the cone meter relatively sensitive to inlet diameter keypad errors.

would induce a traditional flow rate equation prediction error of approximately -3.1%. However, the diagnostics are sensitive to the issue. Figure 14b shows the result.

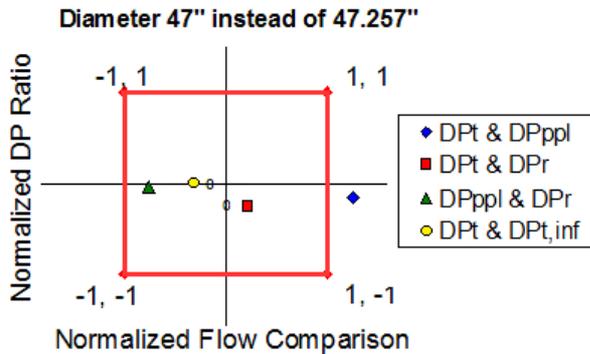


Fig 14b. Inlet Diameter Entered Too Small

In both Figures 14a & 14b note that the DP reading diagnostic (i.e. DPt & DPr,inf) denoted by the yellow circle show correctly that there is no DP reading error. This indicates the malfunction is due to a problem with the meter body (which in this case is the inlet diameter is not the size the flow computer calculation ‘thinks’ it is).

### Incorrect Entry of Cone Diameter

The 48” cone 0.616β meter has a cone diameter of 37.22” / 0.9454m. By way of example, when randomly selecting a baseline / calibration result (i.e.  $Re = 1,270,682$ ) input the cone diameter as not 37.22” but as 38.22”. This too large a cone diameter induces a traditional flow rate equation prediction error of approximately -10.3%. However, the diagnostics are sensitive to the issue. Figure 15a shows the result. Note that the correct cone diameter gave the diagnostic result shown in Figure 13.

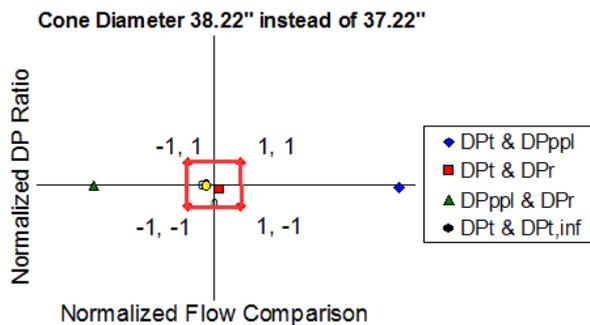


Fig 15a. Cone Diameter Entered Too Large

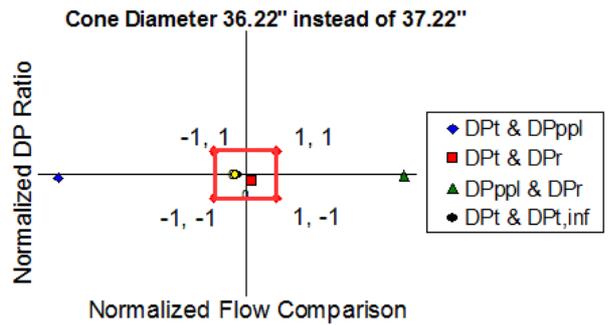


Fig 15b. Cone Diameter Entered Too Small  
Now by way of example, change this cone diameter input so as it is not the correct 37.22” but as an incorrect 36.22”. This too small a cone diameter would induce a traditional flow rate equation prediction error of approximately +10.2%. However, the diagnostics are sensitive to the issue. Figure 15b shows the result.

As with the case for the incorrect cone meter inlet diameter, in both Figures 15a & 15b note that the DP reading diagnostic (i.e. DPt & DPr,inf) denoted by the yellow circle show correctly that there is no DP reading error. This indicates the malfunction is due to a problem with the meter body (which in this case is the cone is not the size the flow computer calculation ‘thinks’ it is).

### Incorrect Entry of Discharge Coefficient

The 48” cone 0.616β meter was correctly calibrated by CEESI to have a discharge coefficient of  $0.7793 \pm 0.5\%$ . If this value is incorrectly entered into the flow computer a bias in the traditional flow rate prediction will result. By way of example, when randomly selecting a calibration result (i.e.  $Re = 1,270,682$ ) input the discharge coefficient not as 0.7793 but as 0.7973. This too large a discharge coefficient induces a traditional flow rate equation prediction error of approximately +2.1%. However, the diagnostics are sensitive to the issue. Figure 16a shows the result. Note that the correct cone diameter gave the diagnostic result shown in Figure 13.

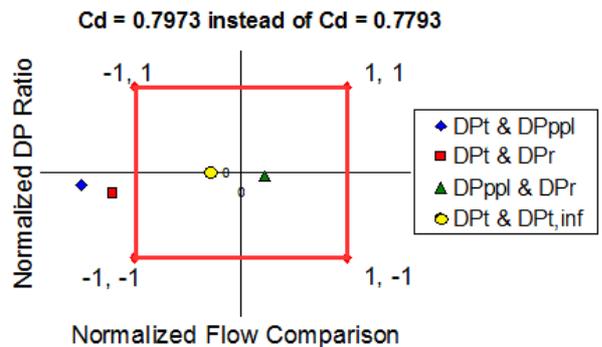


Fig 16a. Discharge Coefficient Too Large.

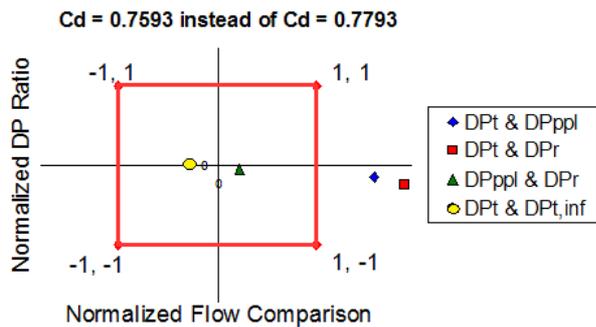


Fig 16b. Discharge Coefficient Too Small.

Now by way of example, change this discharge coefficient input so as it is not the correct 0.7793 but as an incorrect 0.7593. This too small a discharge coefficient would induce a traditional flow rate equation prediction error of approximately -2.7%. However, the diagnostics are sensitive to the issue. Figure 16b shows the result.

As with the incorrect geometry examples the DP reading diagnostic correctly shows the DP's are being read correctly. Note that the diagnostic pattern for the three other DP pairs created by an incorrect discharge coefficient is different to that of a wrong geometry problem. In such ways the diagnostic pattern contains significant information on the nature of the malfunction. However, length constraints means that such a discussion is out with the scope of this paper.

The diagnostic system can also correctly identify a diagnostic system problem if any of the other diagnostic parameters are keypad entered incorrectly. That is, the diagnostic system can self diagnose its own health. However, again, due to length constraints this discussion is out with the scope of this paper.

### DP Reading Errors

Cone meters, like all flow meters, are wholly dependent on their instrumentation being serviceable. Therefore, a common problem is the traditional DP being read incorrectly due to a DP transmitter problem. In this example let us consider the scenario where the DP transmitter reading the traditional DP is over-ranged (or 'saturated'). That is, the actual DP exceeds the maximum DP the transmitter can measure. In this scenario most DP transmitter models on the market read the maximum DP of the range and therefore the DP reading has a negative bias. Hence, if the DP transmitter reading the traditional DP saturates then the traditional flow rate prediction will have a negative bias. Saturation is not the only problem DP transmitters can face. They can drift over time or be incorrectly calibrated. That is, they can produce a positive or negative bias if they are not correctly calibrated or if they drift from that correct calibration. The diagnostic system can see all DP transmitter reading problems.

Take by way of an example, the baseline / calibration data point  $Re = 1,667,100$ . The traditional DP was of course correctly read by CEESI at 2578Pa / 10.37"WC. However, if the DP transmitter had read the DP as 10"WC, i.e. 2486Pa, due to saturation, negative drift or an incorrect calibration, the flow rate prediction would have had a bias of approximately -1.8%. Figure 17a shows the diagnostic result.

Now by way of example, assume that the DP transmitter had read the DP as 10.6"WC, i.e. 26356Pa, due positive drift or an incorrect calibration. The flow rate prediction

**Traditional DP Transmitter Saturated**  
DP = 10"WC instead of actual 10.37"WC

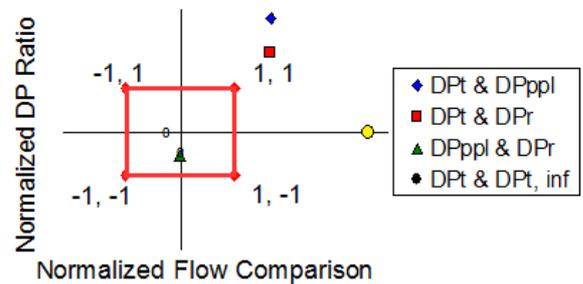


Fig 17a. Traditional DP read low

**Traditional DP Transmitter Drift**  
DP = 10.6"WC instead of actual 10.37"WC

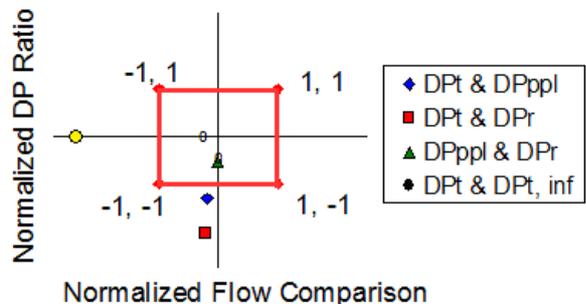


Fig 17b. Traditional DP read high

would have had a bias of approximately +1.1%. Figure 17b shows the diagnostic result.

Both Figures 17a & 17b show that the DP reading diagnostic checks indicate a DP reading error. Therefore, the operator would know the metering system has malfunctioned and that the source of the problem was the integrity of the DP readings. Once this is established the remaining three diagnostic points indicate which DP transmitter has malfunctioned. In both cases the recovered and PPL DP diagnostic pair indicate that there is no problem. In both cases both the traditional & PPL diagnostic pair and the traditional & recovered DP diagnostic pair indicate a problem. The combination of the traditional DP being the communal DP between the two diagnostic points indicating the problem, and the fact that the diagnostic point showing no problem is the only

diagnostic pair to not utilize the traditional DP indicates that the DP reading problem must be with the traditional DP. With the erroneous DP reading identified, and the other two DP readings found as trustworthy, equation 1 can then indicate the correct DP of the erroneous reading. The meter remains in service with the correct flow rate being predicted by the other two DPs (see equations 2 through 4) and / or by the inferred DP from using the two trusted DP readings and equation 1.

In this example the traditional DP reading was discussed. The diagnostic system monitors all three DPs although length constraints deem that such examples are out of the scope of this paper.

## Conclusions

A massed CEESI data set with the calibration results of 141 generic cone meters from four manufacturers has shown that cone meters can be individually calibrated across the applications Reynolds number range to predict the discharge coefficient to  $< 1\%$ , and in the vast majority of cases  $< 0.5\%$ . However, a fitted constant discharge coefficient to that massed data set would only predict the discharge coefficient of any one cone meter to 8.3% uncertainty. Therefore, cone meters should be individually calibrated if the cone meter operator wishes a low uncertainty flow rate prediction.

CEESI can gas flow calibrate extremely large flow meters, such as this 48", sch ST, 0.616 beta ratio cone meter. This calibration showed that this large meters performance was within the performance range of the smaller meters considered in the massed data set.

This CEESI 48", sch ST, 0.616 beta ratio cone meter calibration also showed the capability of the DP Diagnostics cone meter diagnostic system. It was shown that the diagnostic system was capable of monitoring the cone meter performance for various potential problems and gives the operator assurance that the meter is fully serviceable.

## References

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