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Technical Paper

The Performance of Orifice Plate Meters at Low Flows

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1 INTRODUCTION

Despite recent advances in high pressure gas measurement technology, the majority of meter systems on the UK's National Transmission System (NTS) are of the Orifice Plate (OP) design. These systems rely on four key primary measurement components, the orifice plate and carrier assembly, pressure, temperature and differential pressure measurement devices. Usually the meters are operated at flows that are well within the optimal design range of the respective instruments.

Recently, due to the change in NTS demand patterns, there has been a tendency to operate at flows where the differential pressure measurement is below the expected 30-90% range (span) of the instrument. Under these circumstances, the meter system will be operating outside its design envelope. There is a body of circumstantial and limited experimental evidence to suggest that low flow and hence low differential pressures, has a propensity for negative measurement bias (under read) to a magnitude of greater than 2% [1] of absolute reading in some instances.

Although orifice plate flow equation, as defined by ISO 5167, is a continuum across the flow range, its proportionality to the square root of the differential pressure ensures that errors in its measurement will dominate the calculated flow. This is further exacerbated by the instrument's uncertainty at this part of the measurement range. This, coupled with the resolution of the differential pressure instrument, and the inability to validate at these low-pressure values outside a dedicated calibration laboratory, make experimental validation of the low flow phenomena more relevant.

In 2013/14, 57,083 GWh (5,202 mscm) of gas was delivered through meter systems operating at differential pressures below 15 mBar. Without evidence to the contrary and applying the reported negative weighted flow bias of 2% [1] to meters operating below 15 mBar differential pressures, the annual gas under registered is potentially 1,142 GWh. This constitutes 43% of the assessed NTS Shrinkage Unaccounted for Gas (UAG) component at a cost to the Shrinkage budget of ~ £28 m for the same period. This is a considerable potential liability for all users of the NTS.

To explore the behaviour of orifice plate meters under low flow conditions, National Grid embarked on a series of full-scale meter tests to quantify the magnitude of miss measurement.

2 EXPERIMENTAL PROGRAMME

All low flow tests were conducted employing 300mm (12”) diameter OPs with beta ratios of 0.5, 0.6 and 0.7 respectively. These beta ratios being a typical of meter systems operated on the NTS. Each individual plate was subjected to an 11 point test procedure whereby flow measurements were made at differential pressures of 5mBar, 10mBar, 15mBar, 20mBar, 80mBar and 90mBar in both ascending and descending flow directions.

All tests were conducted at the UKAS acredited DNV_GL flow centre at Bishop Auckland using natural gas at typical transmission pressures (>50BarG).

3 RESULTS

Following an initial set of low flow trials, the results indicated that orifice plates operating at low differential pressures exhibited a tendency to under register flow. The magnitude of under registration varies from 1.9% to 0.4% with orifice plates of beta ratios of 0.5 and 0.6 respectively. This was largely consistent with earlier work [1], [2], although the magnitude of the miss measurement was slightly lower. The results from the 0.7 beta ratio test was inconclusive and required further analysis.

The results proved that the two modes of under and over measurement bias were exhibited but the observed behaviour was very dependent on the beta ratio. As such the results for each respective beta ratio are treated separately in the sections below.

3.1 Beta Ratio: 0.5

All 0.5 beta ratio OP tests (Figure 1) displayed under registered flow when operated at differential pressures below 20mBar. This under registration was parabolic in nature with its magnitude increasing from~-0.5% at 20 mBar to ~ -1.75% at 5 mBar.

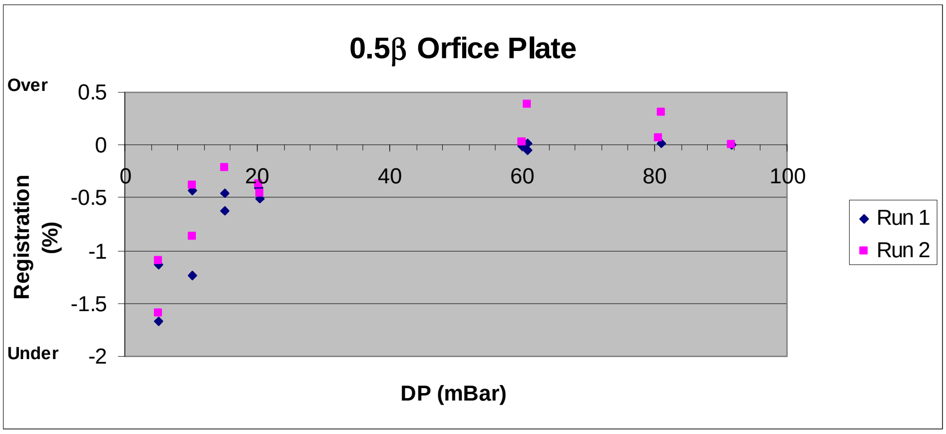

Figure 1. 0.5 β Orifice Plate Low Differential Pressure Test Results.

3.2 Beta Ratio: 0.6

The results at 0.6 beta ratios displayed mixed measurement modes from over to under registration (Figure 2) although the measurement bias was consistent for each respective run. Generally, irrespective of measurement mode, there was a weak parabolic relationship between differential pressure and measurement bias. The range of measurement bias was between -1.8% (under) to 1% (over). The over registration observed in Run 2 (square data points) to 4% (over) is considered to define the outer envelope of measurement behaviour but indicates the large variability of measurement performance over these flow ranges for this meter configuration.

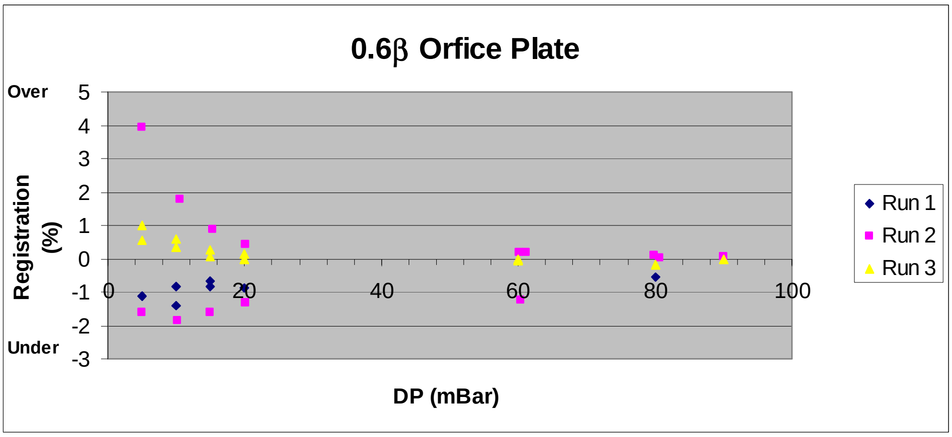

Figure 2. Low Flow Rate Results with 0.6 β Orifice Plate.

3.3 Beta Ratio: 0.7

The measurement results at 0.7 beta ratio again exhibited a mixed mode of measurement bias between under and over registration. There was also a parabolic relationship between differential pressure and flow (as indicated by the parallel curves in Figure 3) but the respective flow relationships appeared to be displaced about the zero (error) registration axis.

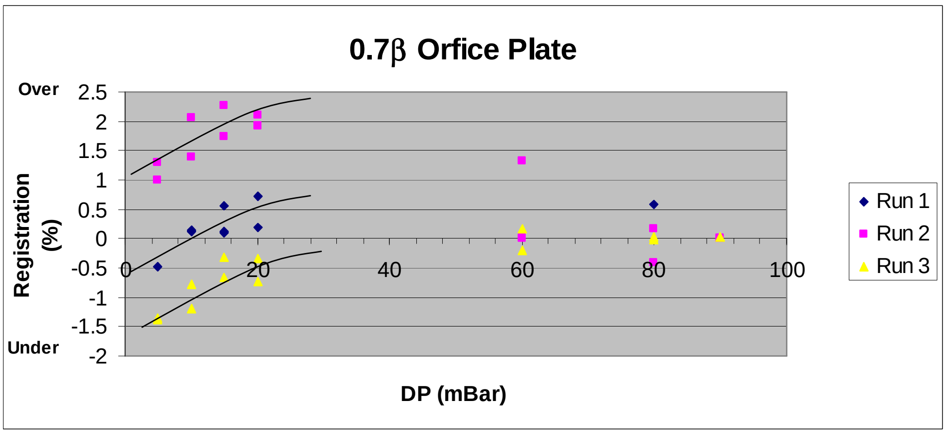

Figure 3. Low Flow Rate Results with 0.7 β Orifice Plate.

4 CONCLUSIONS

- The results for the 0.5 beta ratio plate were consistent with earlier work and confirm the view that these orifice plate metering systems have a tendency to under register at low differential pressures (flows). The magnitude of the under registration is between 1.9 and 0.4% and is considered to be a measurement bias.
- The results for both the 0.6 and 0.7 beta ratio plates exhibited both under and over registration. The sense of the measurement bias (under/over) remained consistent within an individual test sequence but it varied between test runs. The 0.6 beta ratio mix mode data is consistent with other studies [2] although there is no corroborative evidence for the 0.7 beta ratio results.
- This mixed sense measurement bias at the large beta ratios was considered due to the non-optimal development of the gas flow downstream of the OP (vena contracta). Any asymmetric distortion of the flow pattern in this area would affect the differential pressure measurement and consequently the calculated flow. As the flows increase, the flow patterns would become more developed which is likely to reduce asymmetry improving the 'true' differential pressure in that flow region.
- At 0.5 beta ratio it is considered that the flow patterns become more fully developed even at the very lowest differential pressures. The development of the flow pattern and it symmetry leads to a more consistent flow performance.
- All the results are presented in Figure 4 and a measurement bias envelope has been defined and is shown as area enclosed between the solid 'trumpet' lines. The dashed upper trumpet line defines the upper measurement bias.
- The defined envelopes when analysed statistically still indicate the propensity for OP meters to exhibit a negative measurement bias (under read) at low flows.

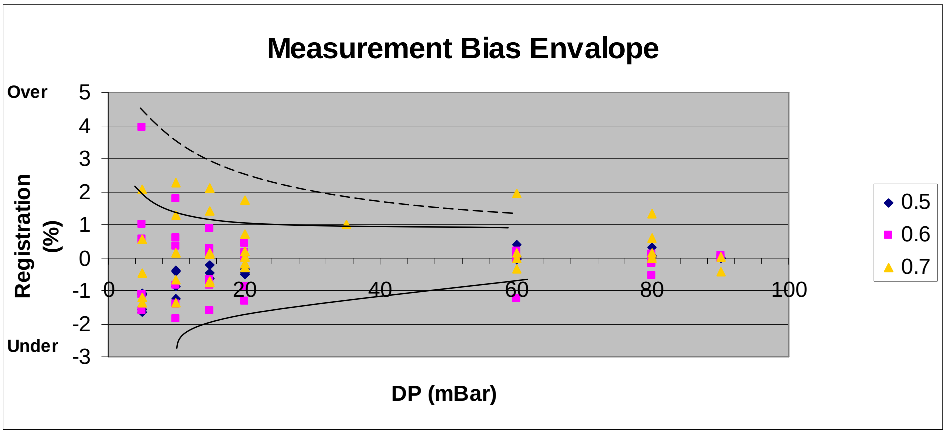

Figure 4. All flow results and the measurement bias trumpets

5 SUMMARY

The completion of the additional analysis confirmed the initial results and these studies will form the central feature of the ongoing meter strategy with all NTS orifice plate asset owners. Some of this articulation strategy has already begun and the reduction in low flow totals for 2013/14 are considered the reflection of the installation of new metering assets and improved flow control of the existing OP asset base.

The wider knowledge of meter performance under low flow conditions also assists the detection and management of UAG and possibly begins to explain its inherent volatility particularly in the summer months.

6 ACKNOWLEDGEMENTS

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7 NOTATION

β Ratio of the bore of the orifice plate d to that of the meter tube diameter D. $\beta = d/D$.

8 REFERENCES

[1] George, D.L. & Hawley, A.G. (2010) *Extended Low Flow Range Metering Final Report.* SwRI Report No. 1815188, PR-015-09605.

[2] George, D. L., Jowers, C.W., and Grimley, T. A., *Assessment of Orifice Plate Flow Measurements with Low Differential Pressures,* Final Report to Pipeline Research Council International. Contract PR-015-08605. April 2009.