

THE EFFECTS OF ORIFICE PLATE METERS WHEN INSTALLED BACKWARDS

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Introduction

Orifice plates when used to measure natural gas flows are usually manufactured with a beveled downstream face. The sharp, square upstream edge on the bore maximizes the pressure drop and the measurement resolution of the orifice meter (Figure 1).

Several studies have found that orifice plates installed backwards can cause under-measurement between 10% and 20%, which is a significant bias and loss for the owner of the product being measured; also warped orifice plates (bent), by comparison, have a smaller effect similar to an error in the measured beta ratio this information was published in 2002 by the GRI and more recently some CFD work performed by Dr Nadezhda Pashnina in the UK.

When an orifice plate with a bevel on the downstream face is accidentally installed backwards, the pressure drop across the plate is reduced, and the flow is under-registered this can cause the flow meter to grossly under register and cause financial loss to the party owning the gas product being metered particularly if the system is managed by a third party who gains benefit from this if not detected quickly. It is incumbent on the operator to detect this error quickly to mitigate losses to the party who owns the gas being transported.

Therefore, it is paramount for both the owner and the third-party transporter contractually responsible for the measurement to write and implement agreed procedures to detect and correct this event as soon as is possible.

If this issue occurs usually in general field locations at custody or allocation points, the usual procedure for correcting the error is to reinstall the plate correctly and use the differential pressures measured before and after reinstallation to estimate the error in flow rate (Witte [1997]). This may be effective however the geometry of the install must match the American Gas Association (AGA) requirements.

Figure 1, below, shows the correct direction and installation parameters for an orifice plate used for custody measurement of Natural Gas based on American Gas Association (AGA) 3 recommendations as used in most USA based pipeline contracts. In overseas markets the ISO 5167 Part 1 and 2 are normally used.

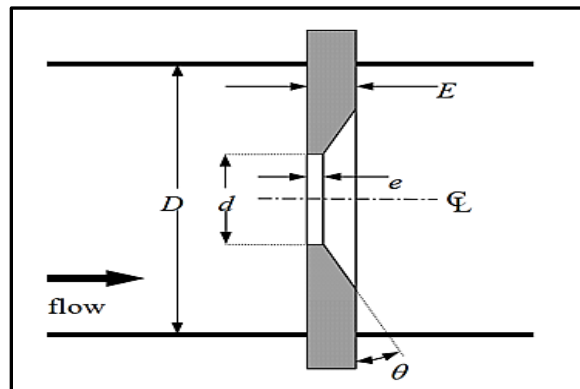


Figure 1. Orifice Plate Flow Meter Parameters (not to scale)

Where: Orifice plate beta or area ratio = β ; Meter tube diameter = D ; Bore thickness = e ; Plate thickness = E .

Flow metering errors for backward orifice plates have been reported by Ting [1993] and Witte [1997] for different orifice meter geometries. Discharge coefficients were also determined for backwards-facing orifice plates in 2-in. and 4-in.-diameter flow lines at the GRI Metering Research Facility, at the time by GRI researchers these results were unpublished at that time.

More tests were performed in the GRI Metering Research Facility in support of AGA Report No. 3, a review of the data from these sources found them to be in general agreement and identified four dimensions affecting a reversed orifice meter discharge coefficient, these being orifice plate β ratio; meter tube diameter, D ; bore thickness, e ; and plate thickness, E (*detail shown in Figure 1.*)

Flow Rate Errors

The flow rate error may also be estimated by calibrating the plate in the reverse direction with a known flow rate using another meter type in series which may not be susceptible to installation effects or removing the meter run and transporting to a laboratory if this is economically viable for example if the meter Volume / MMBtu loss valuations are high deemed applicable.

The alternate method to this maintenance situation is to install a pressure field analysis system, which is very recent in the gas flow measurement field and is being reviewed by standards bodies today “having being accepted” in the EU under ISO 5167 international standards.

This newly developed condition based maintenance system can diagnose in real time issues related to : surface roughness , orifice plate fidelity, incorrectly installed orifice plate direction and eccentricity, DP transmitter issues and leakage across the manifold and also human error based incorrect data being input into a flow computer such as incorrect beta ratio details relative to the installed plate plus leaving a unit in test mode which can occur accidentally after a maintenance visit plus other points available on other technical white papers discussing this technique fully.

The Main Issue

When a measured pressure drop across a reversed orifice plate is accidentally used with a predicted / calibrated forward discharge coefficient to compute the flow rate, the percent change in the discharge coefficient from forward to backward alignment equals the percent error in the flow rate. Flow calibration of backward-facing orifice plates can, only therefore, provide estimates of flow rate error that complement a usual procedure of determination.

More testing and results on the subject were performed in the GRI Metering Research Facility in support of AGA Report No. 3 and have been published in 2000 confirming the previous researchers results to solve this large issue of mis-measurement. Installing a beveled orifice plate backward in an orifice fitting or flange can cause the orifice meter to under-measure the flow rate by as much as 20% depending on beta ratio pipe diameters etc. The effect is similar to rounding the sharp edge of a correctly installed orifice plate which also is cause for concern in a custody transfer application.

Figure 2. Compares the published data sets from the Gas Research Institute Metering Research Facility, (GRI MRF) regarding backward-facing orifice plates in 4-in.-diameter meter tubes against the results obtained by Ting [1993] and Witte [1997] and also the previously unpublished GRI MRF data mentioned earlier in this document.

Two sets of orifice plates were tested at the GRI MRF, having either the minimum or maximum thickness ratio: e/E . (*indicated as this work shown in Fig 2*)

These results showed that orifice plate Set 1, with maximum thickness ratios of $e/E = 0.50$, were in excellent agreement with the earlier MRF 4-in. test results, which used a different set of orifice plates with the same thickness ratios.

Research Data

The data from orifice plate Set 2, with minimum thickness ratios of 0.1, shows larger (more negative) errors than the data from Set 1, indicating that e/E has an important influence on flow rate measurement error for backward installed orifice plates.

For more details concerning the tests on backwards facing orifice plates, refer to GRI Topical Report 01/0074. Table 1. below lists the verified under-measurement errors for the MRF tests in which each plate was installed backwards (each plate error shown represents the average of all flow rates and pressure taps).

One finding of the MRF tests was that the plates with smaller bore thickness consistently gave larger under- measurement errors. The difference between the two error values for a given beta ratio was much larger than the uncertainty due to precision or bias in the facility and was considered significant.

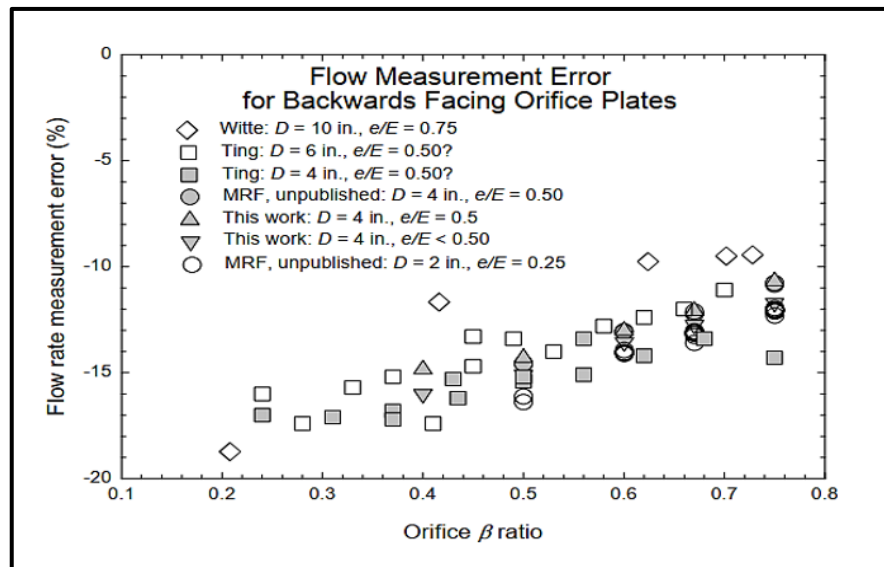


Fig 2. GRI MRF - Reverse Mounted O.P. Measurement Error Research Data

Table 1. Measured Errors for reversed 4-inch diameter orifice plates as tested at the MRF laboratory

β	Set 1, maximum e	Set 2, minimum e
0.40	-14.8%	-16.0%
0.50	-14.3%	-15.1%
0.60	-13.0%	-13.6%
0.67	-12.1%	-12.7%
0.75	-10.7%	-11.7%

Computational Fluid Dynamics

Dr Nadezhda Pashnina in the UK. Performed some work and produced a paper presented at the UK Global Flow Measurement Conference in 2023.

In general, CFD modelling involves four steps: (1) creating the model geometry, (2) creating the mesh (a mesh is the collection of small elements (finite volumes) into which a 3D model geometry is divided, allowing the non-linear partial differential equations governing fluid flow to be solved numerically within each element), (3) defining the physical models by the model setup, and (4) defining the boundary and operating conditions.

Table 2 – Summary of Approaches to CFD Modelling by Dr Pashnina

	NEL	Emerson (SUSU)
CFD Solver Name	ANSYS Fluent	ANSYS CFX, ANSYS Fluent
CFD Solver Version	2021 R1	2019 R3
Plate Geometry	Laser Scanning	Calibration Certificates
Turbulence Model	k- ϵ	k- ω SST
Mesh Type	unstructured polyhedral	structured hexahedral
Number of Elements	40 million	0.5 million
Element Size around Orifice Plate	0.2 mm	0.1 mm
Model Validation in Forward Orientation	ISO 5167-2 [3]	ISO 5167-2 [3]
Model Validation in Reverse Orientation	GRI Report 01/0074 [2]	NSFMW Paper [1]

The full paper is available from the CEESI library in Nunn Colorado listed as in the references.

Earlier CFD was performed using various orifice flow meters with forward and backward-facing orifice plates as also simulated using computational fluid dynamics (CFD) (Morrison [2001]). – data from GRI reports AS mentioned

In addition to the variables examined in the experiments, the ratio of orifice plate thickness to meter tube diameter, E/D , was evaluated in the computational simulations as an influence on measurement error. Figure 14 shows the CFD results for orifice plates with $e/E = 0.50$ installed in 2-, 4-, and 8-in. orifice runs, with β ratios varying from 0.2 to 0.75 and the E/D ratio varying from 1/64 to 1/16.

The effects of E/D were very pronounced, with the results for the three different E/D ratios collapsing to a common curve for each ratio. The errors increased with decreasing β ratio and increasing E/D . This same relationship was implied by the earlier experimental data, where the error increased with decreasing pipe size (for orifice plates conforming to AGA Report No. 3, Part 2 [2000], decreasing D corresponds to increasing E/D ratios).

The computational results, however, showed that there was no effect caused by pipe diameter alone, so the variation in the experimental data with D indicated the cause was by corresponding changes in the E/D ratio. Thos is why it is critical to also confirm that the E/D ratio is correct for each orifice plate used. (Figure 3.)

A good check for the plate quality used, outside of being installed incorrectly is to make sure that a reputable supplier is used that provides geometric measurements for each plate corrected to 68 degrees F or manufactured in a plant that is controlled at 68 degrees F as per the AGA standard requirements and also that the certification shows this data as well as the correct beta ratio and information stamped on the plate itself.

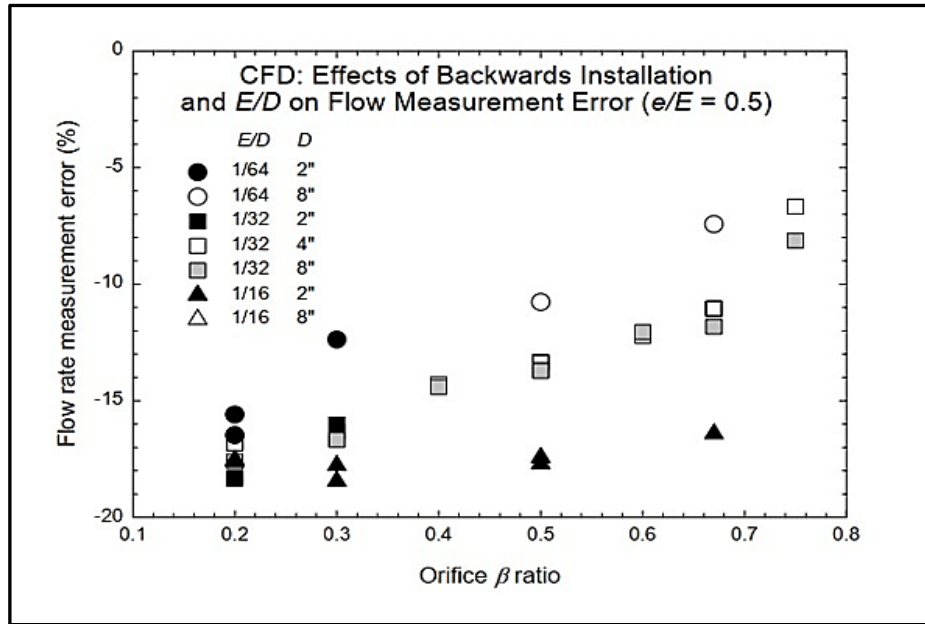


Fig 3. Effect of E/D on measurement error caused by backward installed orifice plates.

Conclusions

The results from the GRI MRF reversed plate research demonstrate that the measurement error caused by a backward-facing orifice plate is (1) a strong function of the orifice β ratio, (2) a moderately strong function of the ratio of orifice bore thickness to plate thickness, e/E , (3) a moderately strong function of the ratio of orifice plate thickness to meter tube diameter, E/D , and (4) a very weak function of Reynolds number.

The GRI research suggests an alternative to the industry procedure for adjusting an erroneous measurement that would be useful if differential pressures with the orifice plate oriented correctly were not available.

Today some Midstream Corporations are using the following equation (Eq 1.) to help determine losses caused by reverse mounted orifice plates in their meter assessment / audits to correct gross under readings.

The correlation helps to simplify the industry's approach to estimating measurement errors resulting from backwards plates. This correlation is further discussed in more detail in GRI Report 01/0074 by George and Morrow.

$$\% \Delta Q = -18.93 + 12.91\beta - 34.04 \left(\frac{E}{D_{nom}} \right) - 8.900 \left(\frac{e}{E} \right) + 13.64 \left(\frac{e}{E} \right)^2 \quad \dots\dots\dots \text{Eq 1.}$$

Typical calculations showing the error values are shown next in Example 1 and Example 2. Indicating the error magnitude for a typical orifice plate meter system with a reverse plate installed.

The best approach is to confirm that the orifice plate is installed the correct direction to prevent such large errors.

Typical Sample Calculations - Backward Installed Plates (*et al* Morrow and George equation)

Inputs		
Nominal Tube Size	2.067	Inches
Orifice Bore $\div$	0.500	Inches
Plate Thickness	0.125	inches
Bore Thickness	0.0625	inches
Intermediate Results		
Beta	0.241896468	
E/D	0.060474117	Plate thickness/Tude Dia.
e/E	0.500	Bore Thickness/Plate Thickness
Measurement Error -18.9% (Under Measurement)		
Multiply measured flow on backward-facing plate by 1.233 to get the actual volume.		

Inputs		
Nominal Tube Size	4.026	Inches
Orifice Bore $\div$	0.500	Inches
Plate Thickness	0.125	inches
Bore Thickness	0.0625	inches
Intermediate Results		
Beta	0.124192747	
E/D	0.031048187	Plate thickness/Tude Dia.
e/E	0.500	Bore Thickness/Plate Thickness
Measurement Error -19.4% (Under Measurement)		
Multiply measured flow on backward-facing plate by 1.241 to get the actual volume.		

Example 1. 2-inch diameter O.P Meter (*Sched 40*) Example 2. 4-inch diameter O.P. Meter (*Shed 40*)

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