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Orifice Meter Installation Effects: Research Update for A' = 29D Meter Tubes.

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Location:	Southwest Research Institute, San Antonio Texas		
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This paper does not provide performance of flow conditioner perforated plates, but it does provide clear evidence as to why the classical 19 tube, tube bundle does nor work. A very good reference paper to show why alternate technologies were developed.

With the new AGA-3 standard being issued soon, this is an excellent reference document to help substantiate the need to change from the existing tube bundle technology to new high performance perforated plates.

97-OP-

Orifice Meter Installation Effects: Research Update for A' = 29 D Meter Tubes

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ABSTRACT

This paper reports results from 4-inch (102 mm) orifice meter installation effects tests performed in the Gas Research Institute (GRI) Metering Research Facility (MRF) High Pressure Loop (HPL). Orifice meter calibrations were performed using a meter tube with an orifice fitting and an upstream length of 29 pipe diameters (D) installed downstream of either a 90° elbow, a tee used as an elbow or two 90° elbows "out-of-plane". Orifice pressure differential measurements were made using both pairs of flange taps located 180° apart on the orifice fitting.

Orifice meter calibration tests were performed in the MRF HPL flowing natural gas at a nominal pressure of 200 psia for five values of orifice β ratio: 0.40, 0.50, 0.60, 0.67 and 0.75. Both bare meter tube tests (without a flow conditioner) and sliding vane tests with a 19 tube bundle straightening vane were performed. C_d measurements were made for two values of Reynolds number for each β value. Reynolds number had a relatively minor effect, and generally only the high Reynolds number results are shown in this paper. This paper compares the 29 D upstream meter tube length results with previous MRF results for a shorter upstream length of 17 D. The complete set of test results is available in a GRI MRF report (1).

INTRODUCTION

The GRI MRF orifice meter installation effects research program is acquiring measurement performance data on several types of orifice meter installations with different flow conditioning devices. The program objective is to investigate the benefit and feasibility of fitting flow conditioners devices into new gas flow metering installations as well as retrofitting these devices into existing metering installations to assure proper upstream flow conditions in orifice meter installations built to conform with A. G. A. Report No. 3, Part 2(2).

GRI MRF Technical Advisory Group members were asked to provide information about the guidelines used by their companies for orifice meter station design. The responses showed that some companies used the recommended minimum values of upstream and downstream meter tube length for $\beta = 0.67$ or 0.75 in Figure 2-5 of A. G. A. Report No. 3, Part 2(2) as a guide. For $\beta = 0.75$, a tube bundle straightening vane would be installed at C = 7 D upstream of the orifice plate in a meter tube with an upstream length, A' = 17 D. However, other companies preferred to use longer upstream meter tube lengths in the range of A' = 22 D to 35 D, while also installing a tube bundle straightening vane.

Previous MRF research(4-7) investigated the effect of varying the 19 tube bundle straightening vane location in short meter tubes with an upstream length of A' = 17 D. Questions were raised whether the experimental results for a short meter tube should be applied also to longer meter tubes. The test results reported in this paper help provide an answer.

BASELINE C_d VALUES

In order to determine the installation error caused by a particular orifice meter installation arrangement, it is necessary to have baseline or reference C_d values for the same orifice diameter ratio, β and Reynolds number. Then the percentage shift in C_d from the baseline value determined in the reference test can be calculated as

$$\Delta Cd = (Cd_{measured} - Cd_{baseline}) / Cd_{baseline}$$

One source for baseline C_d values is the Reader-Harris/Gallagher (RG) equation for orifice coefficient in A. G. A. Report No. 3, Part 1(3). However, an experimental investigation of installation error referenced to the RG equation could be influenced by laboratory bias errors in the calibrations of reference flow meters and transducers that affect only the measured C_d value. It is possible that another flow laboratory, with different experimental biases, wouldn't be able to replicate the experimental results from the first laboratory.

A different procedure, used in this study, allows confirmation by a second laboratory. The procedure requires that both the installation tests and the baseline calibration tests be performed in the same laboratory, using the same orifice plates, over the same flow range, with the same reference flow meters. Then a bias error caused, for example, by a reference flow meter affects both the installation test and the baseline calibration by the same amount. When the C_d values from the baseline test are subtracted from the C_d values measured in the installation tests and normalized as ΔC_d, the effects of laboratory biases are removed.

RANGE OF ACCEPTABLE ΔC_d VALUES

The ideal value for ΔC_d is 0.0%. However, experience in performing baseline calibration experiments in the GRI MRF facilities has shown that baseline C_d values can be repeated to within approximately ± 0.1%. Likewise, an orifice meter installation test would give values of C_d that are repeatable to within about ± 0.1%. Since a baseline C_d value could be at the lower limit of its range, and an installation test could be at the upper limit of its range, it is sensible to set the limit for ΔC_d to be ± 0.2%. In the figures in this paper, dashed lines are drawn for ΔC_d values of +0.2% and -0.2% to indicate the acceptable range of ΔC_d.

For comparisons of ΔC_d values with other laboratories, the ΔC_d limits may be increased slightly to half of the 95% confidence interval in the RG equation, specified in A. G. A. Report No. 3, Part 1(3). This slightly larger acceptance range reflects the greater laboratory to laboratory variability in C_d values found at high and low values of β.

EXPERIMENTAL ARRANGEMENT

Figures 1 and 2 show the experimental arrangement in the MRF HPL for a 4-inch installation effects test with two 90° elbows "out-of-plane" upstream of a meter tube. The test section piping was installed parallel to the HPL manifold section. Valves were placed upstream and downstream of the test piping to isolate the test section from the rest of the loop during piping configuration changes. Figure 1 shows that the gas flow was conducted through an upstream spool piece, 38 D in length, before reaching the inlet to the double 90° elbows, the single 90° elbow, or the tee. A flow conditioner was installed upstream of the 38 D spool piece to remove swirl from the inlet flow. The removal of upstream swirl is particularly important for tests with bare meter tubes.

Figure 2 shows a meter tube with three upstream sections and one downstream section installed downstream of two 90° elbows out of plane. To reduce the upstream length to A = 29 D, the first upstream segment of the meter tube was removed and installed as a downstream segment The same general HPL piping arrangement was used for tests with a single tee or a single 90° elbow upstream of the orifice meter tube.

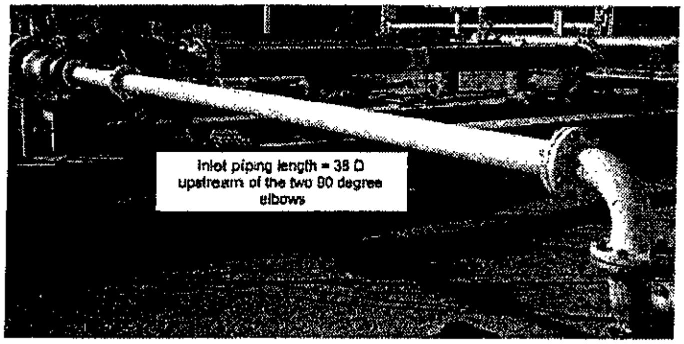

Fig 1. MRF HPL 4-inch diameter piping arrangement upstream of the first of two 90° elbows “out-of-plane”.

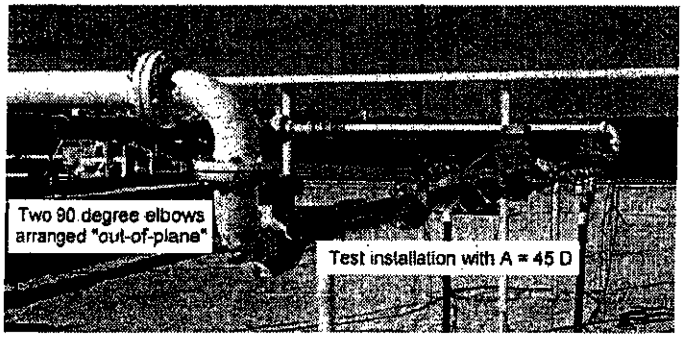

Fig 2. MRF HPL 4-inch , four section orifice meter tube installed downstream of two 90° elbows “out-of-plane”.

A second 4-inch baseline orifice meter was installed downstream of the installation test orifice meter run. The baseline meter run had an upstream length of A = 45 D downstream of an oversized Sprenkle flow conditioner. Baseline C_d values were measured using the same orifice plates, the same pressure and temperature transmitters and the same flow rates, temperatures and pressures as those used in the installation effects tests to eliminate laboratory bias as completely as possible.

TWO 90° ELBOWS “OUT-OF-PLANE”

This installation configuration is shown in Figure 2. The gas flow changes direction by 90° in a vertical plane, then undergoes a second 90° direction change in a second vertical plane perpendicular to the first. The net effect is a resultant 90° turn in a horizontal plane, perpendicular to the two vertical planes, and a change in elevation.

Both 90° elbows were connected together by flange fittings. The straight spacer length between the exit plane of the first elbow and the inlet of the second elbow is about 6-inches, or about s = 1.5 D. Mattingly and Yeh(8) have described the effects of double elbows “out-of-plane” connected by a spacer. When the spacer length, s, between the elbows is relatively small, the double elbow combination produces an intense, single-eddy (type I) swirl that decays slowly in the downstream direction. Increasing the spacer length has the effect of reducing the strength and the initial swirl angle produced by the elbow combination. When the spacer length is large, the swirl ceases to resemble type I swirl, and approaches the double, counter-rotating (type II) swirl that is found downstream of a single elbow. For spacer lengths of s = 2.4 D and 5.3 D, Mattingly and Yeh(8) found that the type I swirl flow pattern dominated the flow downstream of the elbows. We expect the same to be true for the short spacer length, s = 1.5 D, in the MRF tests.

Bare Meter Tube

Figure 3 shows the results of 4-inch MRF HPL bare meter tube tests for A = 17 D and A = 29 D for two 90° elbows out-of-plane, separated by s = 1.5 D. There is not very much difference between the data points for A = 29 D and those for A = 17 D. This indicates that the swirl is decaying very slowly with increasing meter tube length.

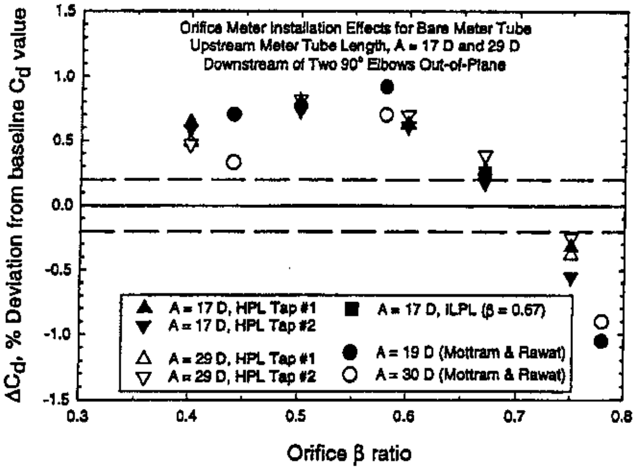

Fig 3. Orifice meter installation effects for bare meter tubes with upstream lengths of A = 29 D and A = 17 D downstream of two 90° elbows “out-of-plane”.

A single data point for β = 0.67 and A = 17 D is shown in Figure 3 from a previous 4-inch Interim Low Pressure Loop (ILPL) test(5). Both the ILPL test and the HPL test used the same double 90° elbow combination. The ILPL data point lies directly beneath the HPL data points for β = 0.67.

For comparison, Figure 3 shows six data points reported by Mottram and Rawat(9) for upstream meter tube lengths of A = 19 and 30 and β values of 0.44, 0.58 and 0.78. Unfortunately, the spacer length, s, between the elbows was not reported, and Mottram and Rawat's experiments were performed for a much lower range of Reynolds number (from Re = 56,000 to 180,000) compared to the MRF HPL tests (Re = 900,000 to 3,600,000) and in pipe that is described as “moderately rusty”(9). The combination of lower Reynolds number and rougher pipe should cause a more rapid rate of swirl decay in the Mottram and Rawat results. Nonetheless, with the exception of the point at β = 0.44 and A = 30 D, the agreement with the MRF HPL data is good.

Meter Tube With 19 Tube Bundle Straightening Vane

For the sliding vane tests, a 4-inch diameter, 19 tube bundle with a cylindrical tube arrangement was attached to a rod that passed through the outside wall of the elbow connected to the meter tube. The rod was calibrated so that the tube bundle location, C, measured from the downstream end of the tube bundle to the orifice plate could be set to different integer values of pipe diameter. Sliding vane tests were performed for β ratios between 0.40 and 0.75, and the results are shown for pressure taps #1 and #2 in Figures 4 and 5. Pressure tap #1 is on the left side of the orifice fitting shown in Figure 2. This tap is aligned along the “inside” of the plane of the 90° bend made by the meter tube, the elbows and the upstream piping. Pressure tap #2 is on the right side of the orifice fitting in Figure 2, along the "outside" of the plane of the 90° bend.

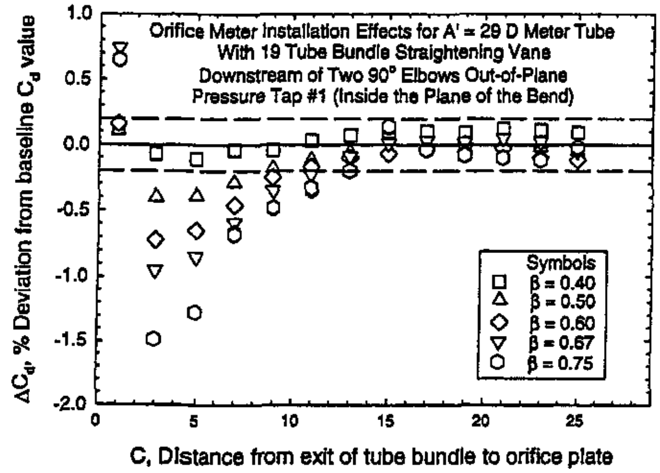

Fig 4. Sliding vane results for tap #1 in an A' = 29 D meter tube downstream of two 90° elbows "out-of-plane".

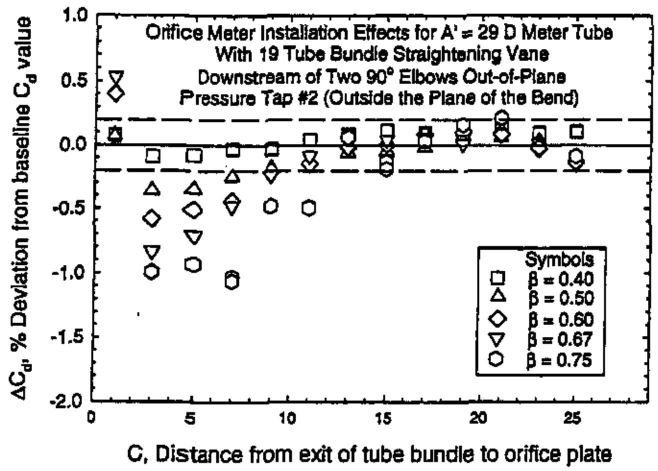

Fig 5. Sliding vane results for tap #2 in an A' = 29 D orifice meter tube downstream of two 90° elbows "out-of-plane".

The test objective was to find the location(s) for the tube bundle where ΔC_d values lie within ±0.2%. Figures 4 and 5 show that the performance goal is reached when the tube bundle is placed at distances between C = 13 to C = 23 upstream of the orifice plate.

Comparison of Sliding Vane Results for A' = 17 D and 29 D

4-inch sliding vane tests were performed with a 19 tube bundle straightening vane in a meter tube with upstream length of A' = 17 D downstream of two 90° elbows "out of plane" flowing nitrogen in the ILPL(5). These tests were limited to a single value of $\beta = 0.67$. The results of the tests with A' = 29 D are compared to the previous results for A' = 17 D in Figures 6 and 7.

The ΔC_d results for A' = 17 D and A' = 29 D are very nearly the same for values of C between 1 and 13. The suggests that the axial and swirl velocity profiles upstream of the tube bundle is relatively unchanged by increasing the upstream length from 17 D to 29 D. This suggestion is plausible since type I swirl decays very slowly at high Reynolds number in smooth meter tubes.

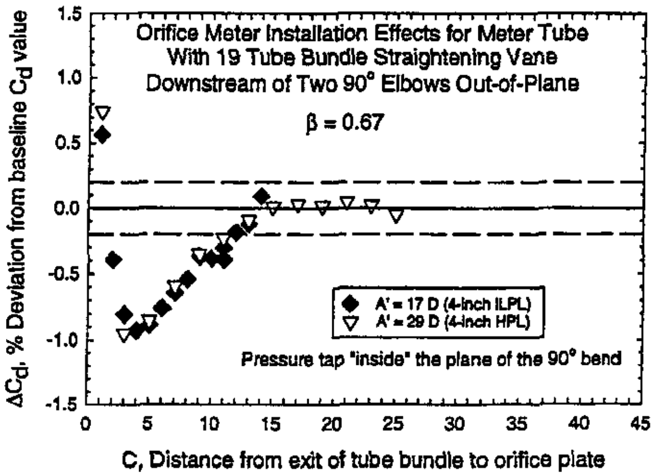

Fig 6. Sliding vane results for pressure tap "inside the plane of the 90° bend" in orifice meter tubes with upstream lengths of A' = 17 D and A' = 29 D downstream of two 90° elbows "out-of-plane".

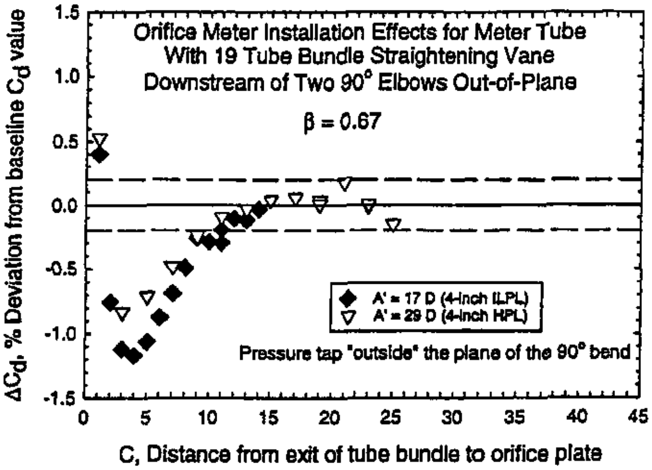

Fig 7. Sliding vane results for tap "outside" the plane of the 90° bend in orifice meter tubes with upstream lengths of A' = 17 D and A' = 29 D downstream of two 90° elbows "out-of-plane".

SINGLE TEE UPSTREAM OF THE METER TUBE

For this test, the double "out-of-plane" elbows shown in Figure 2 were replaced by a single tee. The piping arrangement upstream of the tee was modified by inserting two 90° elbows arranged in an "S" bend to keep the meter tubes at the same elevation above the ground. The S-bend was located downstream of the isolation valve, but upstream of the flow conditioner and 38 D spool piece which was connected directly to the center branch of the tee. The orifice meter pressure tap orientations were left unchanged. Tap #1 was aligned along the inside of the 90° bend formed by the spool piece, the tee and the meter tube. Tap #2 was aligned along the outside of the bend.

Mattingly and Yeh(8) do not specifically address the fluid flow behavior that would be produced by an upstream tee. However, it is likely that a tee will generate a type II swirl flow pattern with two counter-rotating vortices, similar to that produced by a single 90° elbow. Type II swirl decays more rapidly than type I swirl.

Bare Meter Tube

Figure 8 shows the results of the 4-inch HPL bare meter tube tests for A = 29 D downstream of a tee compared with previously published(6) 10-inch HPL bare meter tube results for A = 17. The installation error, ΔC_d, increases strongly with increasing β ratio. For A = 17 D, the magnitude of ΔC_d is less than ± 0.2% for β values of 0.50 or less. For A = 29 D, ΔC_d is less than ± 0.2% for β values of 0.60 or less. For values of β above 0.40, the magnitude of the installation error is reduced by increasing the upstream meter tube length from A = 17 D to A = 29 D.

The variation of ΔC_d with increasing β shown in Figure 8 for the upstream tee is very different than that shown in Figure 3 for two 90° elbows out-of-plane. In both installations, the resultant flow has been turned horizontally by 90°, but the combination of two 90° elbows in perpendicular vertical planes has a much different affect on orifice meter accuracy than either a single tee or a single elbow in a horizontal plane.

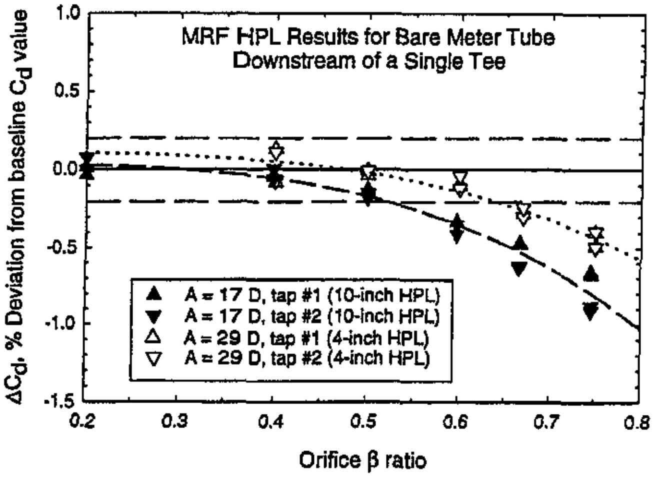

Fig 8. Installation effects for bare meter tube with upstream length of A = 29 D downstream of a single tee.

Meter Tube With 19 Tube Bundle Straightening Vane

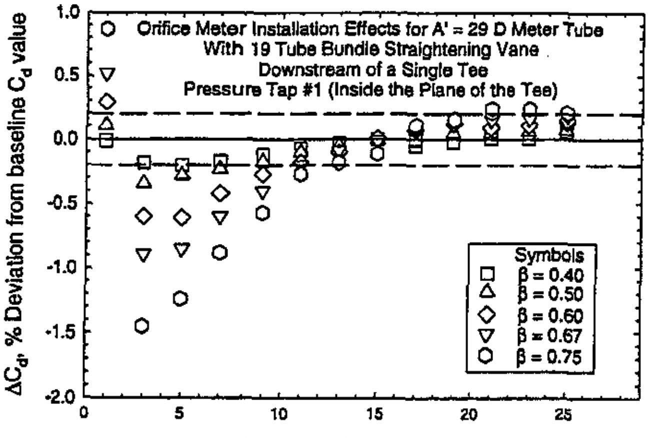

Fig 9. Sliding vane results for tap #1 in an A' = 29 D meter tube downstream of a tee.

A blind flange was fitted to the upstream branch of the tee, and the rod attached to the 19 tube bundle straightening vane was allowed to pass through the blind flange. Sliding vane tests were performed for all five values of β ratio. C_d measurements were made for distances, C, from the downstream side of the tube bundle to the orifice plate, equal to odd integer values (1, 3, 5,...25). The high Reynolds number test results are shown in Figures 9 and 10. The figures show that ΔC_d lies within a range of ± 0.2% for values of C between about 13 and 21. Note that the ΔC_d results are not quite the same for tap #1 and tap #2 for β values of 0.67 and 0.75. That indicates that the velocity profile upstream of the tube bundle is not symmetric about a vertical plane.

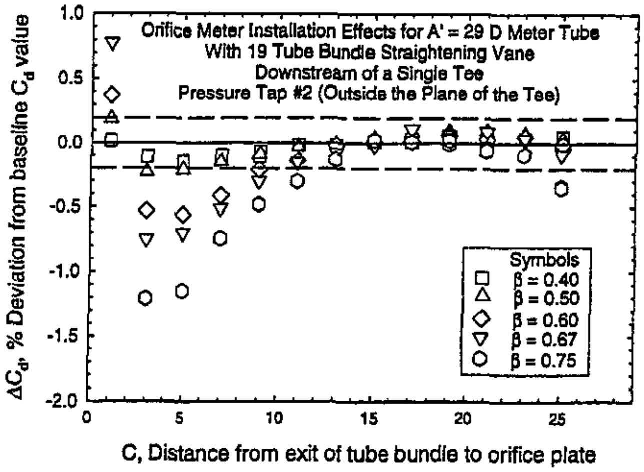

Fig 10. Sliding vane results for tap #2 in an A' = 29 D orifice meter tube downstream of a tee.

Comparison of Sliding Vane Results for A' = 17 D, 29 D and 45 D

Figures 11 and 12 compare sliding vane results for β = 0.67 and for upstream meter tube lengths of A' = 17 D, 29 D and 45 D installed downstream of a single tee. For A' = 17 D, both 4-inch ILPL data(5) and 10-inch HPL data(7) are available. For A' = 45 D, 4-inch ILPL data(6) have been reported.

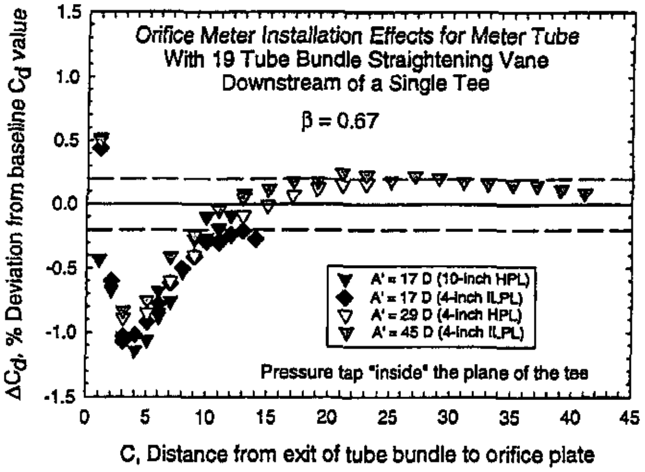

Fig 11. Sliding vane results for pressure tap "inside the plane of the 90° bend" in orifice meter tubes with upstream lengths of A' = 17 D, A' = 29 D and A' = 45 D downstream of a tee.

Figure 11 for pressure tap #1 along the "inside" of the plane in which the upstream spool piece, the tee and the meter tube all lie, shows nearly identical results for all three meter tube lengths for C values between 1 and 10. Between C = 11 and 13, the 10-inch ΔC_d results for A' = 17 D are in good agreement with the 4-inch results for A' = 29 D and 45 D. Between C = 13 and 23, the 4-inch test results for A' = 29 D and 45 D agree well.

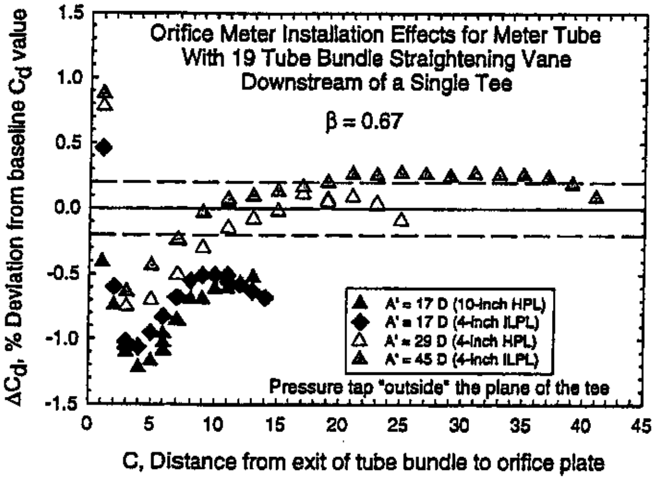

Fig 12. Sliding vane results for tap "outside" the plane of the 90° bend in orifice meter tubes with upstream lengths of A' = 17 D, A' = 29 D and A' = 45 D downstream of a tee.

Figure 12 for pressure tap #2 along the "outside" of the plane of the tee has quite a different appearance. Here the effects of increasing the meter tube length from A' = 17 D to 45 D can be seen clearly. For A' = 17 D, the ΔC_d values never cross the $\Delta C_d = 0.0\%$ axis for values of C greater than 1. However, for A' = 29 D, The installation error crosses the $\Delta C_d = 0.0\%$ axis at approximately C = 15. For A' = 45 D, the crossover point occurs earlier, at about C = 9 D. The different behavior shown in Figure 12 is caused by the more rapid decay of type II swirl downstream of a tee.

SINGLE 90° ELBOW UPSTREAM OF THE METER TUBE

The tee was replaced by a single 90° elbow. Otherwise, the piping upstream of the installation test was left unchanged. The orifice pressure tap orientations were the same as for the test with a single tee used as a 90° elbow.

Mattingly and Yeh[8] found that a single 90° elbow produces a dual-eddy, type II swirl pattern with two counter-rotating vortices on either side of the center plane of the elbow. The vortices generate a strong transverse flow directed toward the outside of the elbow. Mattingly an Yeh[8] found that type II swirl produced by a single elbow had dissipated more than 90% over 20 D of length for a Reynolds number of 100,000. The swirl dissipation rate may be slower at the higher range of Reynolds numbers used in this study.

Bare Meter Tube

Figure 13 shows the results of the 4-inch HPL bare meter tube tests for A = 29 D downstream of a single 90° elbow. Results are shown for both the high Reynolds number and low Reynolds number range test ranges. A small Reynolds number effect can be seen at the higher values of β. The shape of the ΔC_d versus β results are similar to those shown in Figure 8 for the single tee. However, the magnitude of the error for the single elbow is slightly greater than for the single tee. For the single 90° elbow and upstream meter tube length of A = 29 D, ΔC_d is less than ± 0.2% for β values of approximately 0.55 or less.

Meter Tube With 19 Tube Bundle Straightening Vane

Sliding vane tests were performed for all five values of β ratio, and the high Reynolds number test results are shown in Figures 14 and 15. The results are similar to those shown in Figures 9 and 10 for a single tee. For β values less than or equal to 0.67, ΔC_d lies within a range of ± 0.2% for values of C between 13 and 23. For β = 0.75, the variation of C_d values between tap #1 and tap #2 restrict the tube bundle location to 17 D and 19 D.

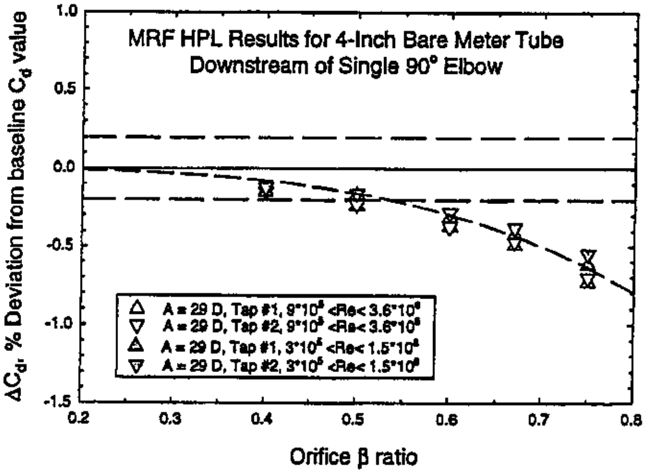

Fig 13. Installation effects for bare meter tube with upstream length of A = 29 D downstream of a single 90° elbow.

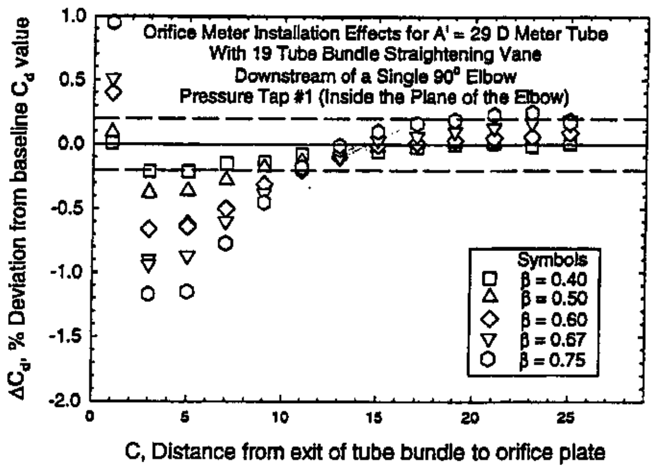

Fig 14. Sliding vane results for tap #1 in an A' = 29 D meter tube downstream of a single 90° elbow.

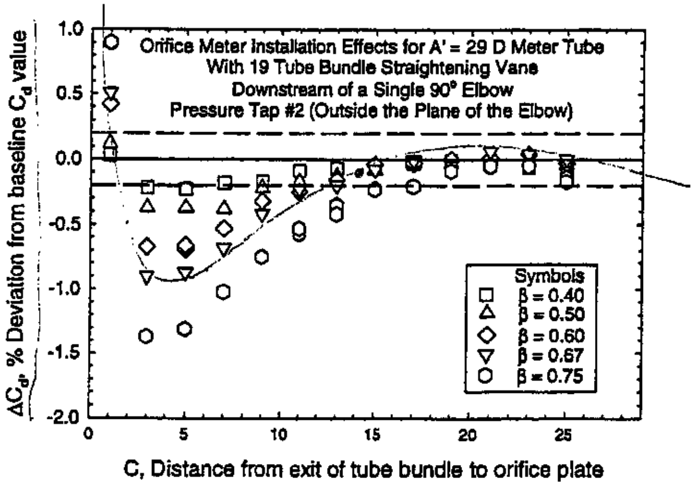

Fig 15. Sliding vane results for tap #2 in an A' = 29 D orifice meter tube downstream of a single 90° elbow.

Comparison of Sliding Vane Results for A' = 17 D and 29 D

Figures 16 and 17 compare sliding vane results for β = 0.67 for upstream meter tube lengths of A' = 17 D and 29 D downstream of a single 90° elbow. The 17 D meter tube data were obtained in the ILPL flowing nitrogen$^{(4)}$ for distances, C, between the tube bundle and the orifice plate of 5 to 13.5. Surprisingly, there appears to be more of a difference in the results measured "inside" the plane of the elbow than "outside". The opposite effect was noted for the upstream tee.

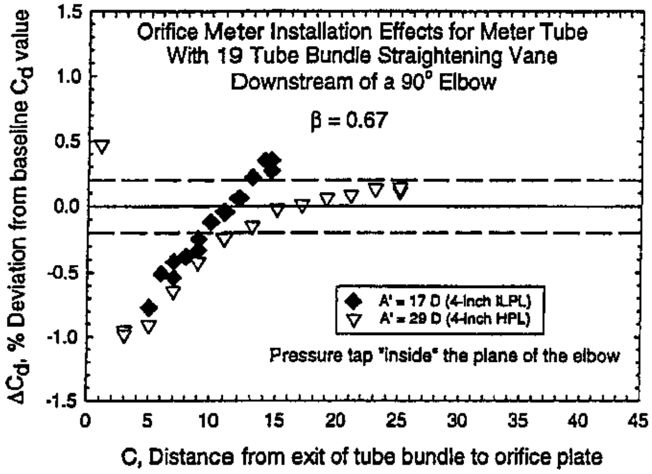

Fig 16. Sliding vane results for tap "inside" the plane of the elbow in orifice meter tubes with upstream lengths of A' = 17 D and A' = 29 D downstream of a single 90° elbow.

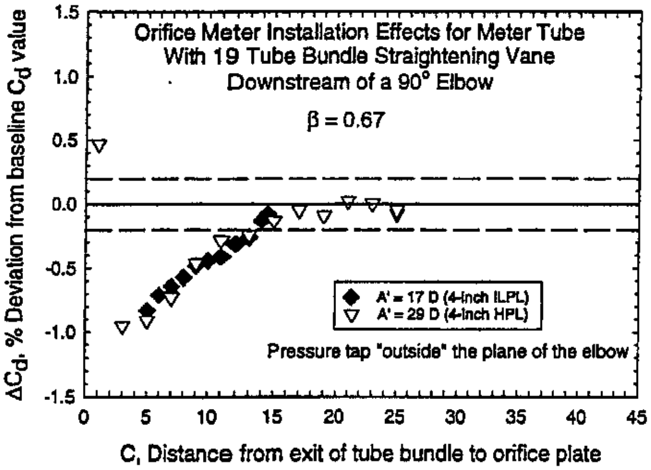

Fig 17. Sliding vane results for tap "outside" the plane of the elbow in orifice meter tubes with upstream lengths of A' = 17 D and A' = 29 D downstream of a single 90° elbow.

CONCLUSIONS AND RECOMMENDATIONS

Very different types of installation errors are produced by double "out-of-plane" elbows than by either a tee or an elbow upstream of a bare meter tube. The type I swirl (double "out-of-plane" elbows) produces mostly positive values of ΔC_d that are not minimized by limiting β ratio. The type II swirl (tee or a single elbow) produces mostly negative values of ΔC_d that can be reduced to a range of ± 0.2% by limiting the upper value of β to about 0.5 or 0.6.

For meter tubes installed downstream of two 90° elbows "out-of-plane", there appears to be no advantage in increasing the upstream length of the meter tube from 17 D to 29 D. This is because the type I swirl decays very slowly. Even when a tube bundle is used to remove swirl from the flow, the velocity profile upstream of the tube bundle is approximately the same independent of the distance from the elbow to the tube bundle inlet. This is why the ΔC_d results in figures 3, 6 and 7 appear to be independent of the upstream length.

For either the single upstream tee or the single upstream 90° elbow, increasing meter tube length from 17 D to 29 D has certain advantages. For bare meter tubes, the installation error is reduced by as much as 0.2% at β = 0.75. For meter tubes with 19 tube bundle straightening vanes, improved performance can be obtained by placing the tube bundle at a distance, C, between 13 D and 23 D for β = 0.67 and at C = 17 or 19 for β = 0.75.

ACKNOWLEDGEMENTS

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