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Optimum Location of Flow Conditioners In a 4 – Inch Orifice Meter

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ABSTRACT

Standards are a framework for ensuring comparable, accurate, and repeatable results. Two orifice flow measurement standards are presently used, one in the United States (ANSI/API 2530[1]) and another in Europe (ISO 5167[2]). These two standards have significantly different specifications for installations. One important specification is the location of the flow conditioner relative to the orifice plate. Several recent European research reports [3,4] have shown that location specifications for flow conditioners in the standards are inadequate. Several different designs of flow conditioners were tested by these laboratories, but these designs are not commonly used in the United States.

As a result of the European findings, the National Institute of Standards and Technology (NIST) began a similar research program to determine the effect of the location of the flow conditioner using flow conditioners commonly used by the U.S natural gas industry. This research was sponsored by the Gas Research Institute (GRI). In this program, a 4-inch stainless steel orifice meter with an upstream surface finish of 0.7 μm (30 μin) was tested in nitrogen gas. Four orifice plates with beta ratios ranging from 0.43 to 0.73 were tested at pipe Reynolds numbers on the order of 10^6. Several types of tube bundle and Sprenkle flow conditioners were tested at five distances upstream of the orifice plate.

This research has shown that when an in-line flow conditioner is located 7 diameters from the orifice plate (the minimum distance specified in ANSI/API 2530[1] for a 0.75 beta ratio plate) the measured discharge coefficient can be as much as 1 percent less than that calculated by ANSI/API 2530[1]. There was no shift in the discharge coefficient for any beta ratio when the in-line tube bundle was located 17 pipe diameters from the orifice plate. The distance between a single elbow and the tube bundle flow conditioner was also found to be insignificant when the conditioner was 17 diameters upstream of the orifice plate.

Key words: discharge coefficient; experimental; flow conditioners; flow measurement; gas; orifice meter; velocity profile

LITERATURE REVIEW

In 1952, Clark[5] published a paper of practical recommendations for the measurement of flow with orifice meters. He cited research that was performed in 1931 and showed that flow conditioners attenuate swirl, but cause their own flow disturbances. The use of flow conditioners was not encouraged, since 5 to 20 pipe diameters would be required between the flow conditioner and the orifice plate, depending on the beta ratio.

Kinghorn[6] extensively reviewed the literature on the effect of flow disturbances on orifice flow measurement and on the use of flow conditioners, including the etoile, Sprenkle, Zanker, and tube bundle. Sprenkle's paper[7] combined the installation recommendations of the Joint A.G.A.-ASME Committee of Orifice Coefficients and other research up to 1945. He made recommendations for the lengths upstream and downstream of common installations with and without flow conditioners installed. Sprenkle recommended an egg-crate type of flow conditioner.

The most recent studies on the location of flow conditioners relative to orifice plates were published by Smith[3] and by Humphrey and Hobbs[4]. Smith's paper summarizes an extensive research program at three European laboratories (Gasunie, National Engineering Laboratory (U.K.), and Delft Hydraulic Laboratory) to determine the optimum location of a Sprenkle, Zanker, and several types of tube bundles in a 100 mm and a 250 mm orifice meter. Smith concluded that 7 diameters of straight pipe were sufficient downstream of a Sprenkle or Zanker flow conditioner in a 250 mm pipe for beta ratios less than 0.57. For beta ratios

greater than 0.57 in a 250 mm pipe and beta ratios less than 0.57 in a 100 mm pipe, the Sprenkle and Zanker conditioners would require 25-30 diameters. The optimum location for the tube bundle flow conditioner for both line sizes was found to be between 10 and 15 diameters, or greater than 40 diameters.

Humphrey and Hobbs[4] tested the following five types of flow conditioners in water in a 200 mm orifice meter with a 0.8 beta ratio plate: Zanker, Mitsubishi, etoile, Air Moving and Conditioning Association (AMCA), and a tube bundle[1]. Each flow conditioner was tested in three types of flow: swirling, asymmetric, and fully developed turbulent flow. Humphrey and Hobbs concluded that all of the flow conditioners except the tube bundle dissipated the flow disturbance to less than 1 percent when the flow conditioners were located 10 diameters from the orifice plate and 2 diameters from the disturbance. The tube bundle had 130 tubes 12 mm (1/2 in) in diameter and had a length of 2 pipe diameters. The typical tube bundle used in the U.S. has 19 tubes and a length of 2-1/2 pipe diameters. The velocity profile was very flat and resulted in errors in the discharge coefficient as large as 10 percent.

The results of Smith's[3] and Humphrey and Hobbs'[4] research prompted GRI and NIST to begin a research program on flow conditioner location effects emphasizing common U.S. flow measurement practice. Sindt, et al.[8] presented preliminary results from this research program in 1986. This report is a complete compilation and analysis of NIST research on location of flow conditioners in non-swirling flow conditions. Recommendations for improving the flow measurement standards are also made.

EXPERIMENTAL PROGRAM

The mass flow reference facility [9,10] at NIST in Boulder, Colorado was used to test the flow conditioners in a 4-inch stainless steel orifice meter. The orifice meter had flange taps, and the differential pressure was measured with pressure transducers. The upstream section of the orifice meter had a surface finish (R_a) of 0.7 μm (30 μin) and a length of 11.5 pipe diameters. The surface finish was prepared by honing the meter; this resulted in a consistent circular pattern. The operating conditions in the gas test section were nominally 4.1 MPa (600 psia) and 289 K (60°F).

A tube bundle and a Sprenkle flow conditioner were tested at specific locations upstream of the orifice plate. Appendix A lists the specifications of the flow conditioners. At some locations, an in-line type of flow conditioner was installed and at other locations, a flanged type flow conditioner was installed.

The following three types of tube bundles were tested:

1) In-line with a round pattern;
2) Flanged with a round pattern;
3) Flanged with a hexagon pattern.

Both an in-line and a flanged Sprenkle flow conditioner were tested. Table 1 lists the different configurations tested for each flow conditioner. Drawings of the installations are given in figure 1. A maximum of four beta ratios were tested in each installation. The tests were usually repeated on different days using a statistically designed test plan to assure confidence in the data.

[1]Names of flow conditioners are given to identify and distinguish between designs. No endorsement of the company or the design is implied by NIST or the U.S. Government.

Table 1. Flow Conditioners and Installations Tested

Configuration Number*	Flow Conditioner	Oversized Sprenkle Installed at the Elbow	Distance from Flow Conditioner to Orifice Plate	Distance from Elbow or Oversized Sprenkle to Flow Conditioner	Beta Ratio 0.43	0.55	0.67	0.73
2	None	No		58D	X	X	X	X
3	In-line Tube Bundle	No	7D	10D	X	X	X	X
4		No	7D	48D		X		X
10		Yes	11.5D	35D	X			X
11		Yes	11.5D	32.5D		X	X	X
12		Yes	17D	27D	X		X	
13		No	17D	38D		X		X
14		No	17D	0D	X	X	X	X
15		Yes	27D	17D	X		X	
16		No	27D	28D		X		X
7	Flanged Tube Bundle Round Pattern	No	9D	47D	X	X	X	X
8		No	11.5D	44D	X	X	X	X
11	Flanged Tube Bundle Hexagon Pattern	Yes	11.5D	32.5D			X	X
5	In-line Sprenkle	No	7D	10D	X	X	X	X
6		No	7D	48D		X		X
9	Flanged Sprenkle	No	11.5D	45D		X		X

*See figure 1

The coding in the legend of the following plots specifies the number of pipe diameters between the flow conditioner under test and the orifice plate, and then specifies the number of pipe diameters between the elbow or the upstream flow conditioner. Table 2 gives a brief description of the codes.

Table 2. Codes for Flow Conditioner and Installation

OS	-	Oversized Sprenkle
IS	-	In-line Sprenkle
IT	-	In-line tube bundle
FT	-	Flanged tube bundle (round pattern)
FHT	-	Flanged tube bundle (hexagon pattern)
E	-	Elbow

Configurations with no flow conditioner at the elbow are coded in the figures as 'E xx D' where 'xx' is the number of pipe diameters from the elbow to either the orifice plate or the flow conditioner under test. For example, if the code is 'IT 7 D, E 10 D', then the in-line tube bundle is located 7 diameters upstream of the orifice plate and 10 diameters downstream of the elbow. The oversized Sprenkle was a nominal 6-inch diameter unit with a 6 to 4-inch reducer immediately downstream of the Sprenkle flow conditioner. The number of pipe diameters from the Sprenkle conditioner was determined by measurement from the 4-inch end of the reducer, since the reducer was considered to be part of the flow conditioner assembly. The oversized flow conditioner was never used as a test element but was used only to remove any flow disturbances caused by the elbow.

EXPERIMENTAL RESULTS

All of the experimental tests were performed in a 4-inch orifice meter with gaseous nitrogen as the test fluid at a pipe Reynolds number ranging from $3X10^5$ to $1.7X10^6$. The surface finish (Ra) of the upstream meter tube was 0.76 μm (30 μin). The following results are based on these operating conditions. The quantity, CY_2, was calculated using measurements of mass, time, static pressure, temperature, differential pressure, and the dimensions of the orifice meter and plate. The discharge coefficient, C, was then calculated from this quantity using the equation for the expansion factor (Y_2) from ANSI/API 2530[1]. Differences in the discharge coefficient are considered to be statistically significant only if the differences are greater than 2 standard deviations (95 percent confidence limits).

The first set of tests were to determine whether there was a significant difference between the discharge coefficients for: (a) an orifice meter installed with an oversized Sprenkle located 47 pipe diameters upstream of the orifice plate (configuration 1) and (b) an orifice meter installed with 58 pipe diameters of straight pipe between the elbow and the orifice plate (configuration 2). Both configurations produced a fully developed turbulent profile. The data with the oversized Sprenkle located at 47 pipe diameters upstream of the orifice plate is used as the baseline for comparison of all the tests. Figures 2 through 5 show the comparison between the data on configurations 1 and 2. For all four beta ratios, no statistical difference between the two configurations was found.

The next two configurations involved testing the in-line tube bundle 7 pipe diameters upstream of the orifice plate. In the first test, there were 10 pipe diameters between the elbow and the in-line tube bundle (configuration 3) and for the second test there were 48 pipe diameters (configuration 4). The data from these tests are plotted in figures 6 through 9.[2] There was no significant difference between the two data sets; this suggests that installing 10 pipe diameters between the elbow and the flow conditioner has the same effect as installing 48 diameters. However, there was a significant difference between the baseline data and the data at 7 pipe diameters.

[2] Four data points in figure 6 and three data points in figure 9 are suspected to be outliers and were left off the plots. These points are included in the tables in appendix B.

Identical tests were conducted using an in-line Sprenkle flow conditioner (configurations 5 and 6). The results are shown in figures 10 through 13. The change in the discharge coefficient is in the same direction, but of a larger magnitude than with the tube bundle. Again there is no difference in the discharge coefficient between the data with 10 and with 48 pipe diameters between the elbow and the flow conditioner. Table 3 lists the percent difference between the linear least squares curve fit of the baseline data and the 7 pipe diameter location data on the in-line tube bundle and in-line Sprenkle at a pipe Reynolds number of 10^6.

Table 3. Percent difference in discharge coefficient between the baseline data and data at the 7 diameter location for the in-line tube bundle and the in-line Sprenkle at a pipe Reynolds number of 10^6.

$$\text{Beta Ratio} \qquad \% \text{ Difference} = \frac{(C - C_{baseline})}{C_{baseline}} \times 100$$

Beta Ratio	Tube Bundle	Sprenkle
0.43	-0.4	-0.4
0.55	-0.6	-0.8
0.67	-0.9	-1.1
0.73	-1.3	-1.8

The next location tested was with a flanged tube bundle 9 pipe diameters from the orifice plate. There was a distance of 47 pipe diameters between the elbow and the flanged tube bundle (configuration 7). The data for this location for all four beta ratios are shown in figures 14 through 17. These data are lower than the baseline data except for the 0.67 beta ratio plate.

The flanged tube bundle was then inverted and installed in the approach section with the flange at the downstream end. The distance from the plate to the tube bundle was 11.5 pipe diameters. There was a distance of 44 pipe diameters between the elbow and the flanged tube bundle (configuration 8). Data for this configuration are plotted in figures 18 through 21. For all beta ratios, the data for the flanged tube bundle at 11.5 diameters was the same as the baseline data.

The flanged Sprenkle conditioner was installed at the same location as shown in configuration 9. Two beta ratios were tested and both showed significant differences in the discharge coefficient. The 0.55 and 0.73 beta ratio plates had an average difference of -0.8 and -1.6 percent, respectively. Figures 22 and 23 are plots of the data.

An oversized Sprenkle was installed upstream of the in-line tube bundle shown in configuration 10. In order to install the in-line tube bundle at 11.5 diameters, a 2 diameter spool piece was placed between the upstream and approach sections. The in-line tube bundle was installed in the spool piece with the end protruding into the approach section. The approach and upstream sections were usually pinned together. In this arrangement, neither section was pinned. Two beta ratio plates were tested, 0.43 and 0.73. Data for the 0.43 beta ratio plate showed no difference from the baseline data, whereas the data for the 0.73 beta ratio plate showed a -1 percent difference (figures 24 and 25).

Since the discharge coefficient for the flanged and in-line tube bundles was significantly different on the 0.73 beta ratio plate at 11.5 pipe diameters, additional testing was required. The flanged tube bundle used prior to this point had a round pattern. A flanged tube bundle with a hexagon pattern was then tested in configuration 11 to determine whether there was a difference between tube bundle designs. The hexagon patterned tube bundle was tested with the 0.67 and 0.73 beta ratio plates. No significant difference in the discharge coefficients are seen on the 0.67 beta ratio plate (figure 26), whereas data for the 0.73 beta ratio lay 0.25 percent below the baseline (figure 27).

An additional test was performed to determine whether the difference in the data with the in-line tube bundle at 11.5 diameters was due to the actual flow conditioner or to the alignment of the spool pieces which were not pinned. The in-line tube bundle was installed in the approach section without the use of the 2 diameter spool piece (configuration 11). The upstream and approach sections were then pinned as usual. Three beta ratios were tested and the results are shown in figures 28 through 30. The discharge coefficient for the 0.73 beta ratio plate was 0.4 percent larger in this configuration than when the in-line tube bundle was in the spool piece. Therefore, it is surmised that the alignment of the pipes also had a significant effect on the discharge coefficient at the 11.5 diameter location. The discharge coefficient was lower than the baseline for all beta ratios and was an average of 0.3 percent below the baseline data for the 0.55 and 0.67 beta ratio plates.

The in-line tube bundle was also tested at 17 pipe diameters. The oversized Sprenkle conditioner was installed upstream of the tube bundle flow conditioner for beta ratios of 0.43 and 0.67 in configuration 12. No flow conditioner was installed upstream of the tube bundle in configuration 13 and all the beta ratio plates were tested. The results are shown in figures 31 through 34. There is no significant difference between the baseline data and these data for all beta ratios. There is also no difference between whether the oversized Sprenkle or the elbow was upstream of the flow conditioner. Seventeen diameters is the closest location relative to the orifice plate for which there was no significant difference for all beta ratios.

The effect of upstream pipe length was tested by installing the tube bundle at the elbow and maintaining the length between the tube bundle and the orifice plate (configuration 14). These results are also shown in figures 31 to 34. The data clearly show no difference between configurations 12, 13 and 14 for all beta ratios.

The in-line tube bundle was also tested at 27 pipe diameters. The 0.43 and 0.67 beta ratio plates were tested in configuration 15, and the 0.55 and 0.73 beta ratio plates were tested in configuration 16. The 0.43 and 0.55 beta ratio data did not differ significantly from the baseline data, but the 0.67 and 0.73 beta ratio plates differed by 0.4 to 0.5 percent. In this case, the effect was to increase rather than decrease the discharge coefficient. This is the first location where the discharge coefficient was increased. The results are shown in figures 35 through 38.

The discharge coefficient and the pipe Reynolds number data at each location downstream of the in-line tube bundle were fit for each beta ratio. The percent change in discharge coefficient was evaluated from the fit at the Reynolds number shown in figures 39 through 42. The error bars represent the 95 percent confidence interval of the mean. Smith's[3] data are also plotted. A negative percent change indicates that the actual discharge coefficient is lower than the baseline coefficient. These plots clearly show a significant change in the discharge coefficient when the in-line tube bundle is located at 7 pipe diameters from the orifice plate. The optimum location for all beta ratios at these operating conditions is at 17 pipe diameters.

Figures 43 through 46 show the same information expressed as the percent difference between the experimentally determined discharge coefficient and the coefficient calculated from ANSI/API 2530[1] at a pipe Reynolds number of 10^6. Again, a negative percent change means that the measured discharge coefficient is lower than the calculated coefficient.

For the 0.43 beta ratio plate, figure 43, there is a 0.3 percent change at 7 diameters, which is within 2 standard deviations of the ANSI/API 2530 coefficient. For the 17 and 27 diameter locations, there is a 0.1 percent change in the discharge coefficient, which is less than one standard deviation and is insignificant.

The 0.55 beta ratio plate shows a significant effect at all tested locations, where the percent change is three or more standard deviations from the value calculated by the standard. At 7 diameters, the discharge

coefficient is 0.8 percent below the predicted value. The data for the 0.67 beta ratio plate also shows a significant difference from the standard at all tested locations (figure 45). The maximum difference is -1.0 percent at 7 diameters.

The largest change was determined with the 0.73 beta ratio plate. At 7 diameters the percent change is greater than -1.0 and at 27 diameter the percent change has increased to +0.9. At 11.5 and 17 diameters, the discharge coefficient was 0.3 percent below the predicted value. These experimental measurements have confirmed that the location of the flow conditioner relative to that of the plate is a critical parameter.

VELOCITY PROFILE

Velocity profiles were measured at four locations downstream of two tube bundle flow conditioners and the oversized Sprenkle conditioner. Traverses were made through the pressure tap holes on the orifice meter with a directional pitot tube. The orifice meter had 12 mm (1/2 in) tap holes on each side of the pipe. A plate with a beta ratio of 1.0 was installed in the orifice meter. Measurements were made in the horizontal plane. An in-line tube bundle was located at 7 and 27 pipe diameters, a flanged tube bundle was located at 11.5 diameters, and an oversized Sprenkle conditioner was located at 47 diameters upstream of the measurement point. Both tube bundles had a round pattern. Figures 47 through 50 are plots of the measured velocity profiles at a Reynolds number 1.1×10^6. The dashed line represents the fully developed turbulent velocity profile calculated from equation 1 from Schlichting[11].

$$\frac{u}{\bar{u}} = C \left[\frac{Y}{R}\right]^{1/n} \qquad (1)$$

where:

u = point velocity
$\bar{u}$ = mean velocity
C = constant = 1.177
Y = radial distance
R = radius of the pipe
n = 8.8 at Reynolds number = 1.1×10^6.

All data points were taken in a random order and measurements were repeated at several radial locations. The velocity profile was changed by the tube bundle flow conditioner and developed to a fully developed turbulent profile as the tube bundle was moved away from the measurement point.

CONCLUSIONS

The results of this research for a 4-inch orifice meter confirm that the discharge coefficient depends upon the location of the flow conditioner. The test results show that the current specifications for the location of a tube bundle flow conditioner are not adequate for a 4-inch meter.

The most significant conclusions from this flow conditioner location study are:

(1) At 7 pipe diameters, the discharge coefficient was significantly lower than both the baseline data and the predicted value from ANSI/API 2530 for all beta ratios.

(2) The error in the discharge coefficient increased with increasing beta ratio.

(3) The type of tube bundle (hexagon, flanged, in-line) installed at 11.5 diameters affected the discharge coefficient differently for the largest beta ratio plate.

(4) At 11.5 diameters, a significant difference was found between configurations 10 and 11.

(5) Data for the flanged tube bundle at 11.5 pipe diameters were statistically the same as the baseline data for all beta ratios (with a distance of 44 diameters installed between the elbow and the flanged tube bundle).

(6) Data for the in-line tube bundle at 17 pipe diameters were statistically the same as the baseline data for all beta ratios.

(7) There was no difference between installing the in-line tube bundle at the elbow or 37 diameters downstream of the elbow when there were 17 diameters between the in-line tube bundle and the orifice plate.

(8) There was no significant difference in the orifice discharge coefficient between an installation with no flow conditioner and 58 diameters between the elbow and the orifice plate, and an installation with an oversized Sprenkle flow conditioner at the elbow and 47 diameters upstream of the orifice plate.

(9) When the Sprenkle or tube bundle conditioners were located 7 diameters upstream of the orifice plate, there was no difference between installing the flow conditioner 10 or 48 pipe diameters away from the elbow.

(10) Only for a beta ratio of 0.73 was where a difference found between the round and the hexagon-pattern flanged tube bundles.

(11) The Sprenkle flow conditioner had a significant effect on the orifice discharge coefficient when located at 11.5 pipe diameters or closer. No other locations were tested.

(12) Locating the tube bundle at 27 pipe diameters upstream of the orifice plate made the orifice discharge coefficient as much as 0.5 percent higher than the baseline for plates with beta ratios of 0.67 and 0.73.

Humphrey and Hobbs'[4] data on the effect of a tube bundle flow conditioner showed as much as 10 percent error in the discharge coefficient. This effect may be attributable to the different designs of tube bundles. The ANSI/API standard[1] specifies only the maximum tube diameter (1/4 the diameter of the pipe) without specifying a minimum diameter. Humphrey and Hobbs' 200 mm (8 in) tube bundle with 130 12 mm (1/2 in) tubes and the 4-inch tube bundle tested in this study with 19 12 mm (1/2 in) tubes both lie within the specifications of ANSI/API 2530[1]. Intuitively, the 130 tubes would produce a far different velocity profile than would 19 tubes. Also, according to ANSI/API 2530[1], Humphrey and Hobbs' tube bundle would need to have been only 125 mm (5 in) long.

Smith[3] recommended that the tube bundle be located between 10 and 15 pipe diameters or more than 40 pipe diameters upstream of the orifice plate. He also suggested that the Sprenkle conditioner should be located between 25 and 30 pipe diameters from the orifice plate. The conclusion based on the tube bundle agrees well with the results of this NIST/GRI research program.

RECOMMENDATIONS

All work reported here was performed in a 4-inch meter with an upstream surface finish (R_a) 0.76 μm (30 μin). For this type of orifice meter, the length requirement in the standards between the flow conditioner and the orifice plate need to be increased. For the conditions tested, a distance of 17 diameters was the optimum location for all beta ratios. The effect of the flow conditioner was mitigated at this location. The distance between a single elbow and the flow conditioner can be eliminated. Therefore, the overall length can be maintained at 17 diameters (plus the flow conditioner) with the flow conditioner repositioned.

The specification on the design of the tube bundle in ANSI/API 2530 needs to be revised and upgraded so that flow conditioners will all produce relatively the same velocity profile. An additional constraint is necessary on either the tube diameter or the number of tubes.

Further research is needed to determine the interdependence of meter size, surface finish, and flow conditioner location. The effect of different specifications for manufacturing tube bundles including the number, length, and surface finish of the tubes should also be determined. Methods of installing and positioning in-line flow conditioners also need to be evaluated.

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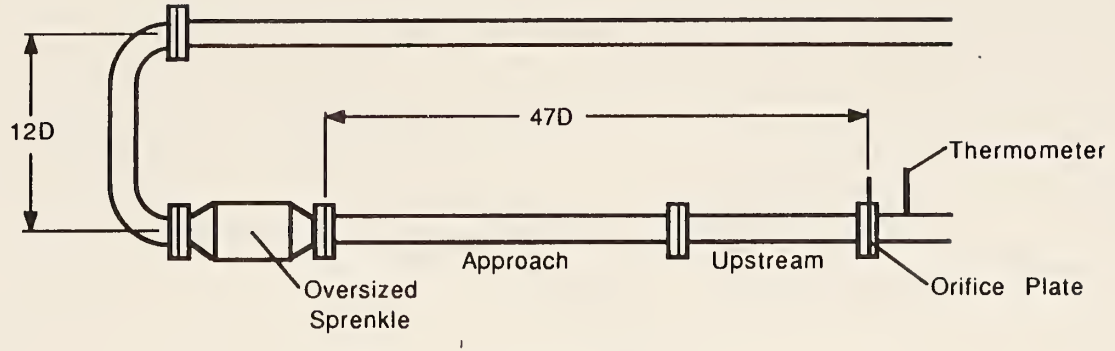
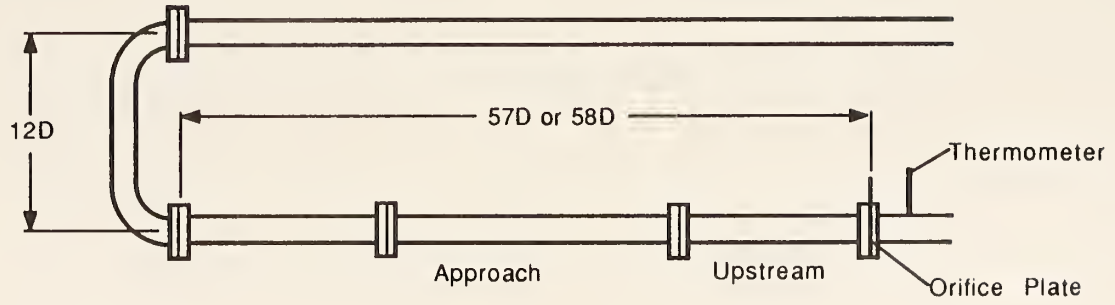
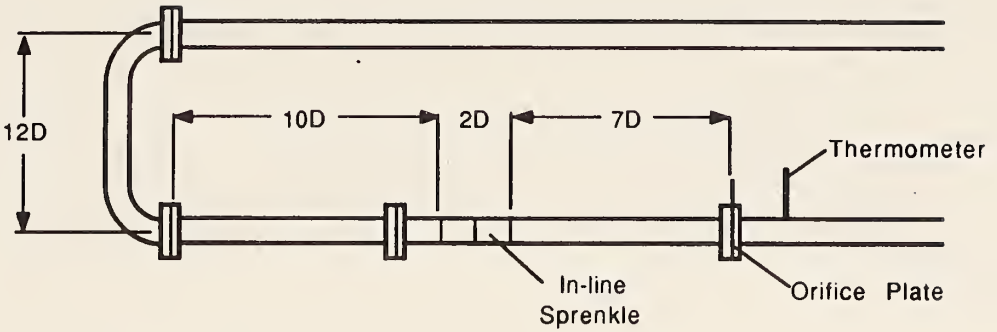


Configuration 1

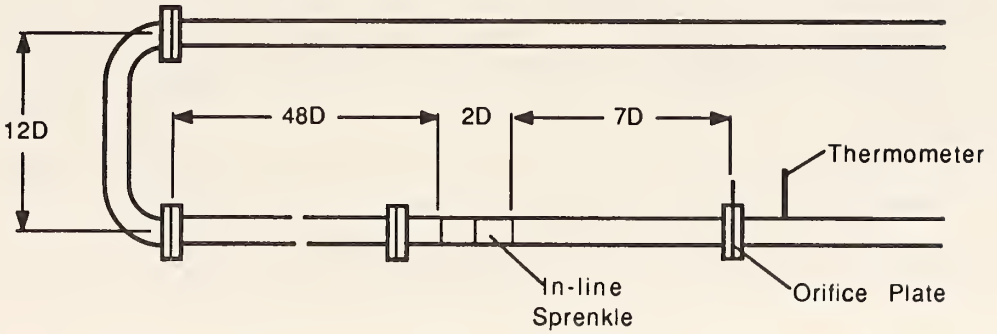


Configuration 2

Figure 1a. Configurations of gas flow test section for flow conditioner location tests.

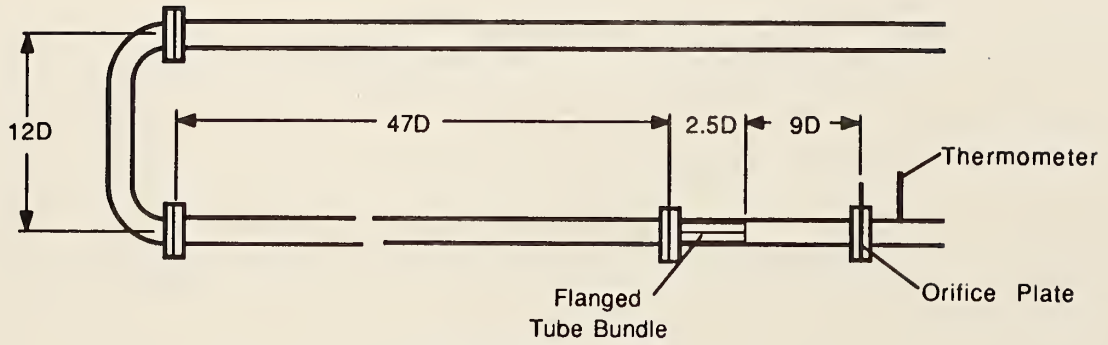


Configuration 5



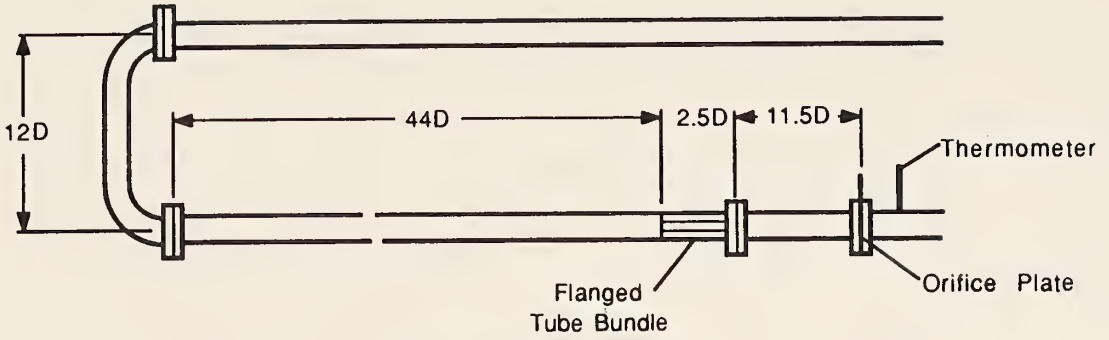
Configuration 6

Figure 1c. Configurations of gas flow test section for flow conditioner location tests (continued).

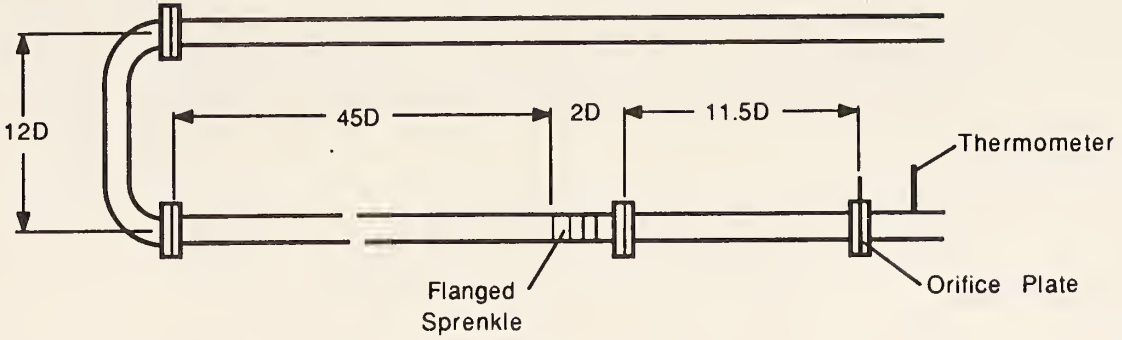


Configuration 7

Figure 1d. Configurations of gas flow test section for flow conditioner location tests (continued).

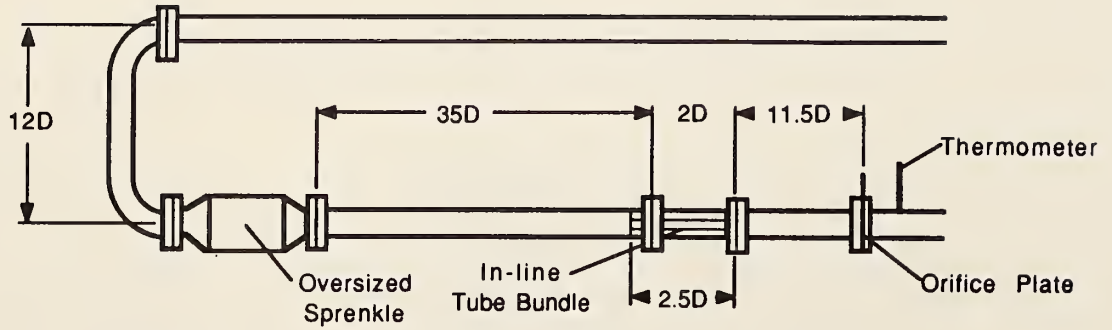


Configuration 8

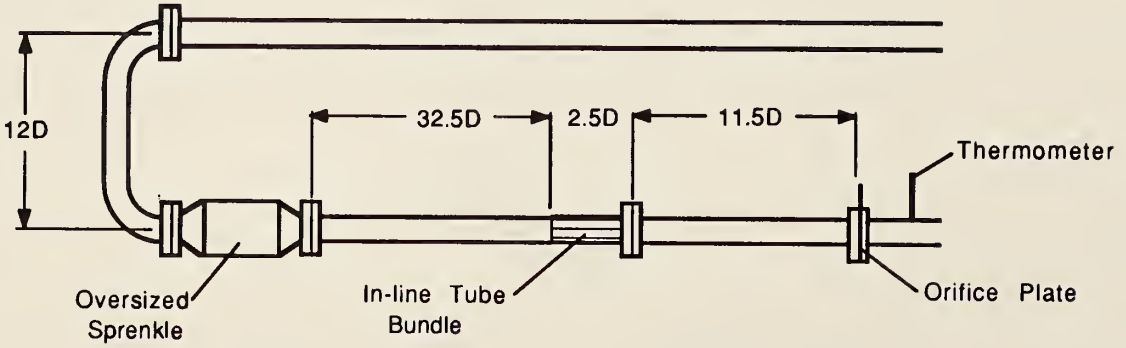


Configuration 9

Figure 1e. Configurations of gas flow test section for flow conditioner location tests (continued).

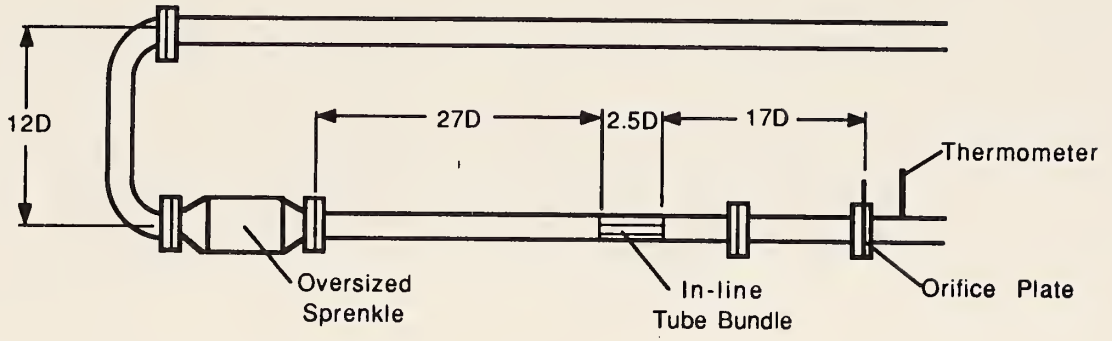


Configuration 10

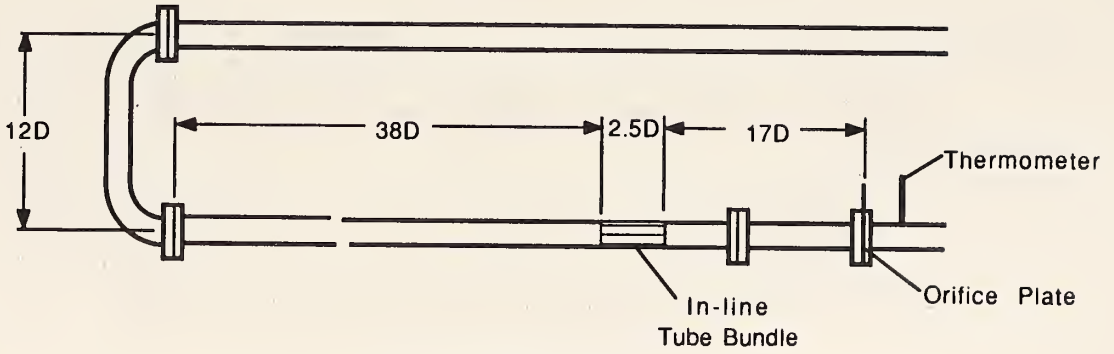


Configuration 11

Figure 1f. Configurations of gas flow test section for flow conditioner location tests (continued).

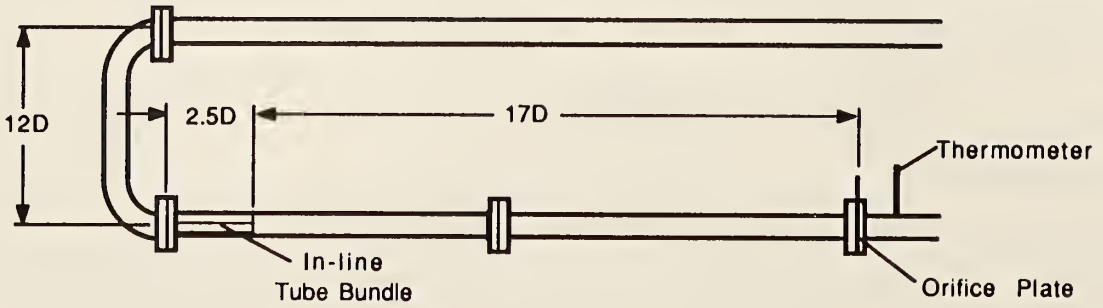


Configuration 12



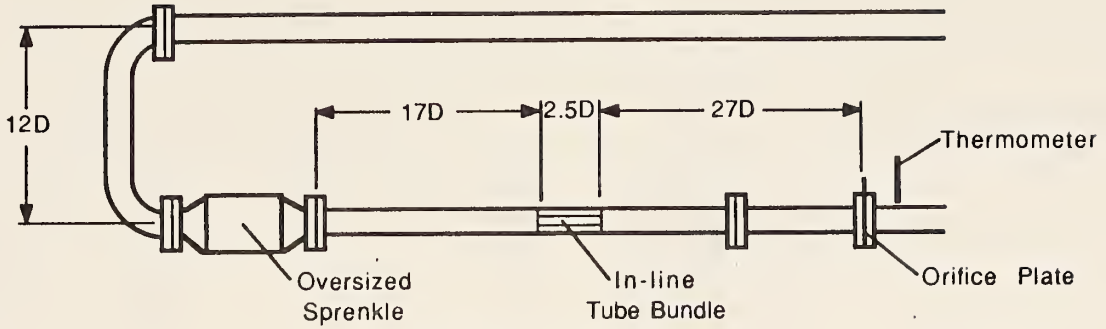
Configuration 13

Figure 1g. Configurations of gas flow test section for flow conditioner location tests (continued).

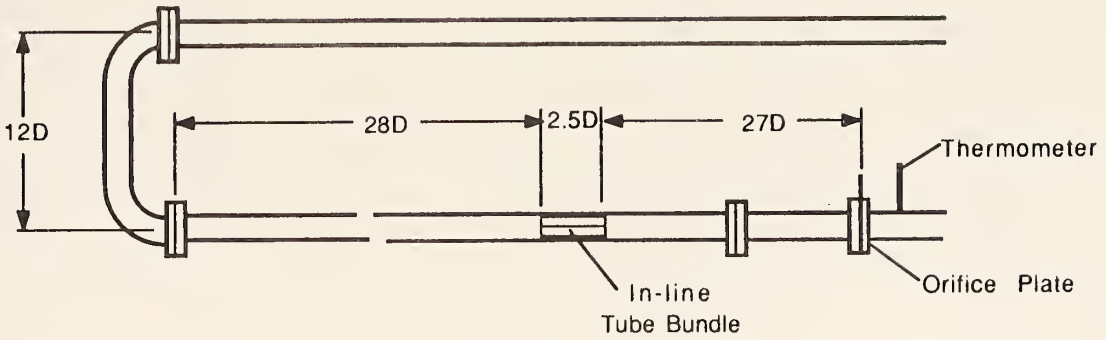


Configuration 14

Figure 1h. Configurations of gas flow test section for flow conditioner location tests (continued).



Configuration 15



Configuration 16

Figure 1i. Configurations of gas flow test section for flow conditioner location tests (continued).

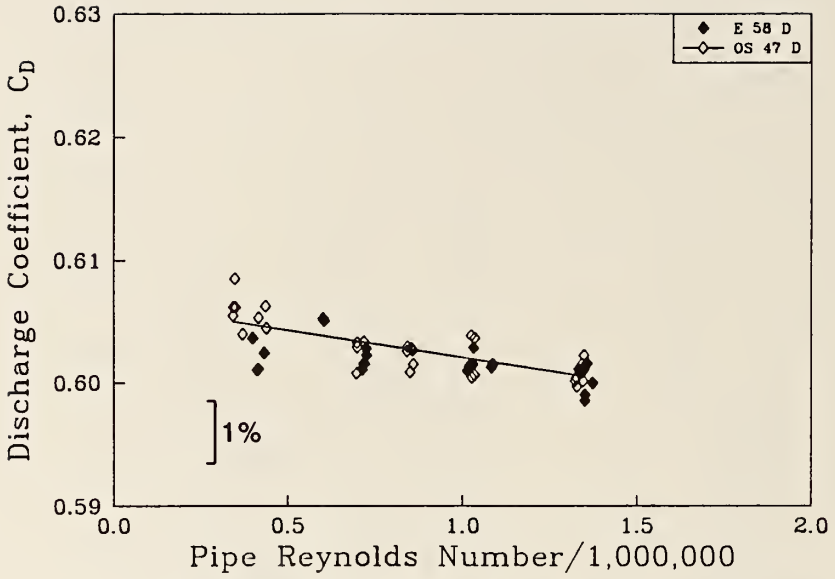


Figure 2. Discharge coefficients of a 0.43 beta ratio orifice meter in Configurations 1 and 2, 58 diameters from the elbow to the orifice plate and 47 diameters from the oversized Sprenkle to the orifice plate.

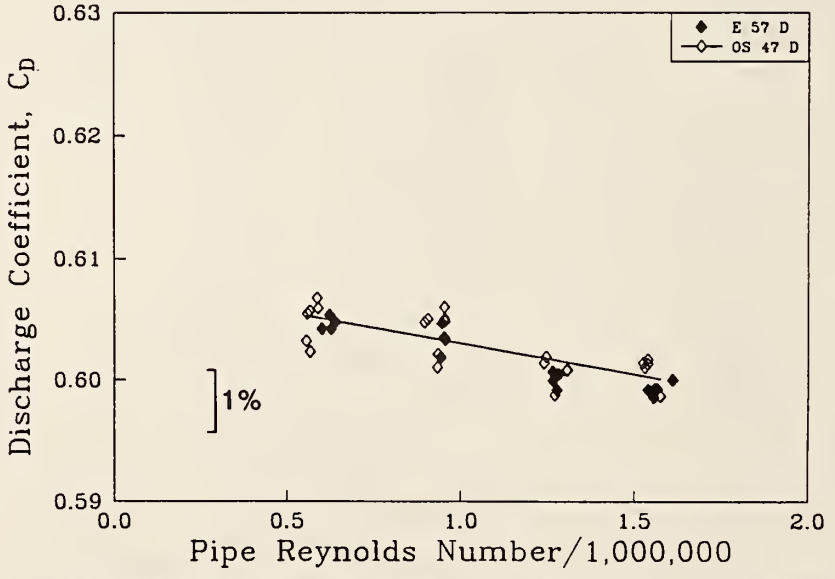


Figure 3. Discharge coefficients of a 0.55 beta ratio orifice meter in Configurations 1 and 2, 57 diameters from the elbow to the orifice plate and 47 diameters from the oversized Sprenkle to the orifice plate.

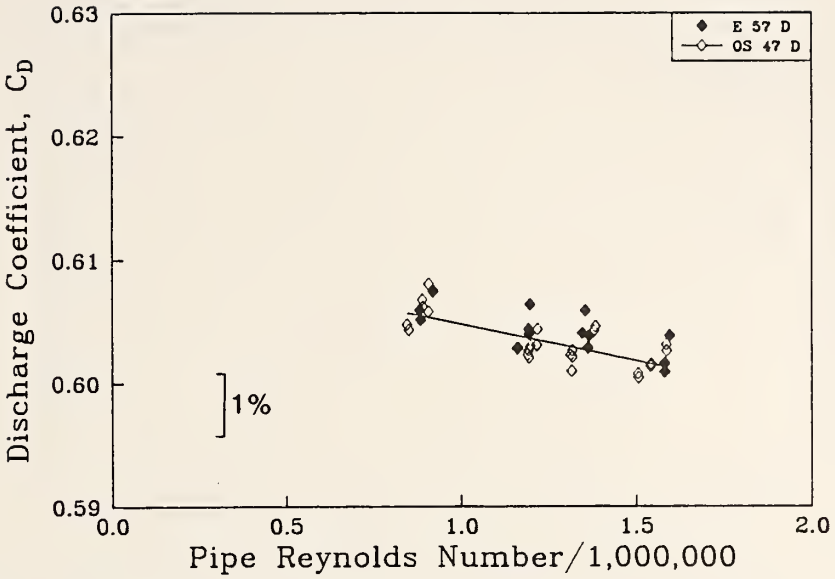


Figure 4. Discharge coefficients of a 0.67 beta ratio orifice meter in Configurations 1 and 2, 57 diameters from the elbow to the orifice plate and 47 diameters from the oversized Sprenkle to the orifice plate.

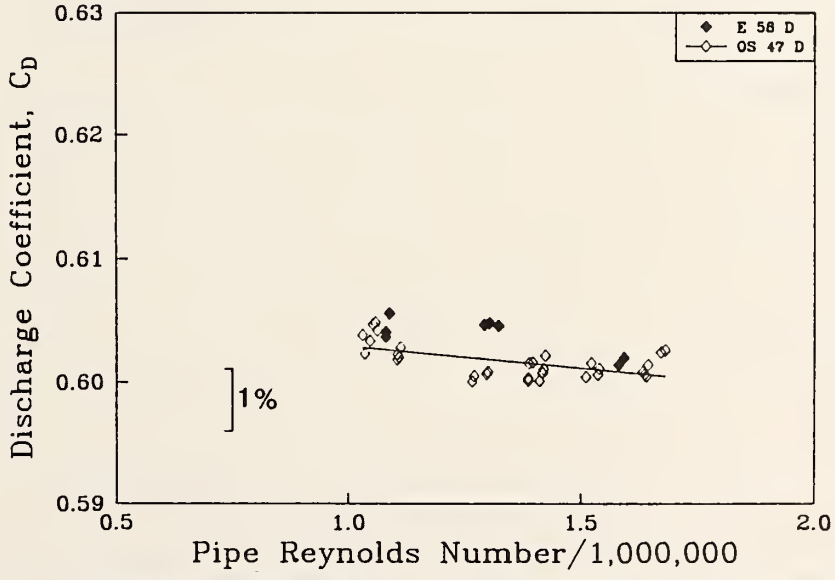


Figure 5. Discharge coefficients of a 0.73 beta ratio orifice meter in Configurations 1 and 2, 58 diameters from the elbow to the orifice plate and 47 diameters from the oversized Sprenkle to the orifice plate.

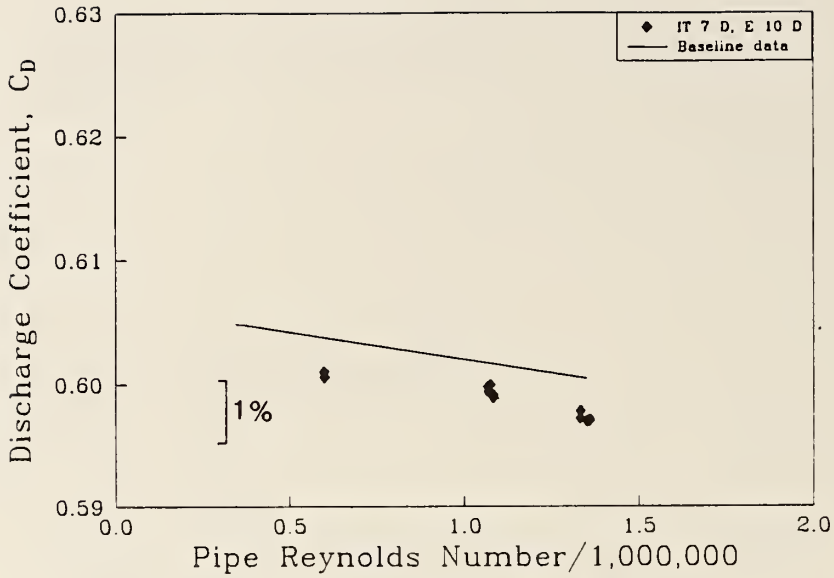


Figure 6. Discharge coefficients of a 0.43 beta ratio orifice meter in Configuration 3, 7 diameters from the in-line tube bundle to the orifice plate and 10 diameters from the elbow to the in-line tube bundle.

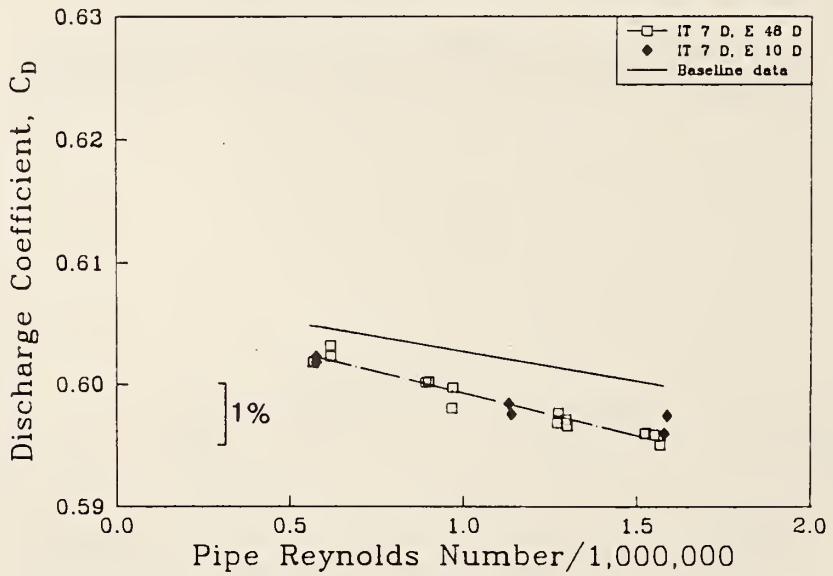


Figure 7. Discharge coefficients of a 0.55 beta ratio orifice meter in Configurations 3 and 4, 7 diameters from the in-line tube bundle to the orifice plate and 10 or 48 diameters from the elbow to the in-line tube bundle.

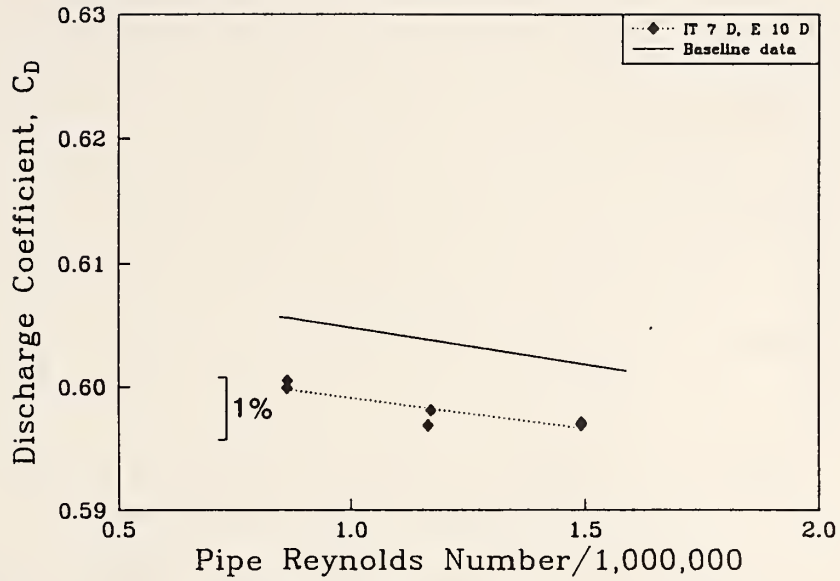


Figure 8. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 3, 7 diameters from the in-line tube bundle to the orifice plate and 10 diameters from the elbow to the in-line tube bundle.

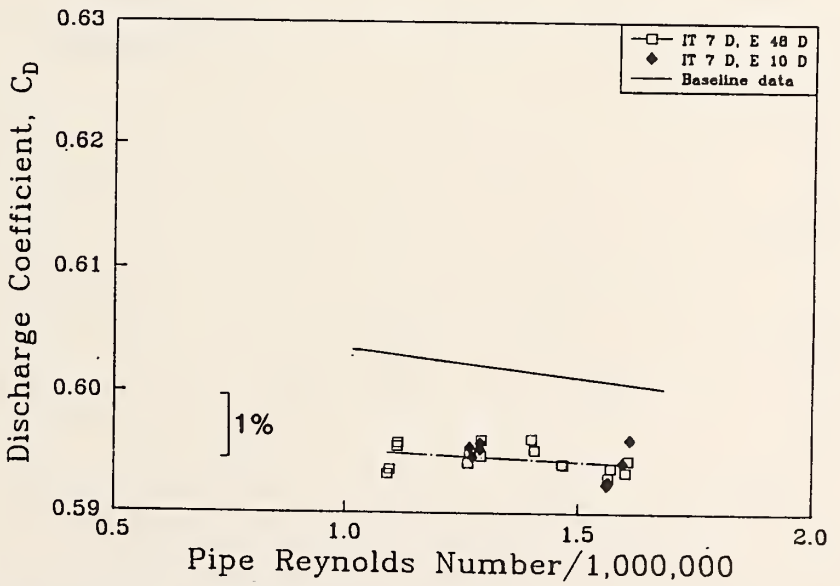


Figure 9. Discharge coefficients of a 0.73 beta ratio orifice meter in Configurations 3 and 4, 7 diameters from the in-line tube bundle to the orifice plate and 10 or 48 diameters from the elbow to the in-line tube bundle.

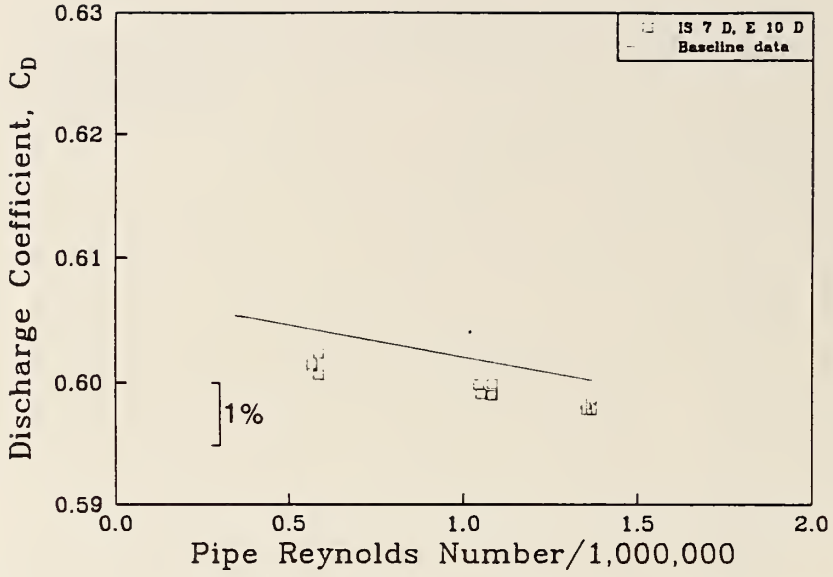


Figure 10. Discharge coefficients of a 0.43 beta ratio orifice meter in Configuration 5, 7 diameters from an in-line Sprenkle to the orifice plate and 10 diameters from the elbow to the in-line Sprenkle.

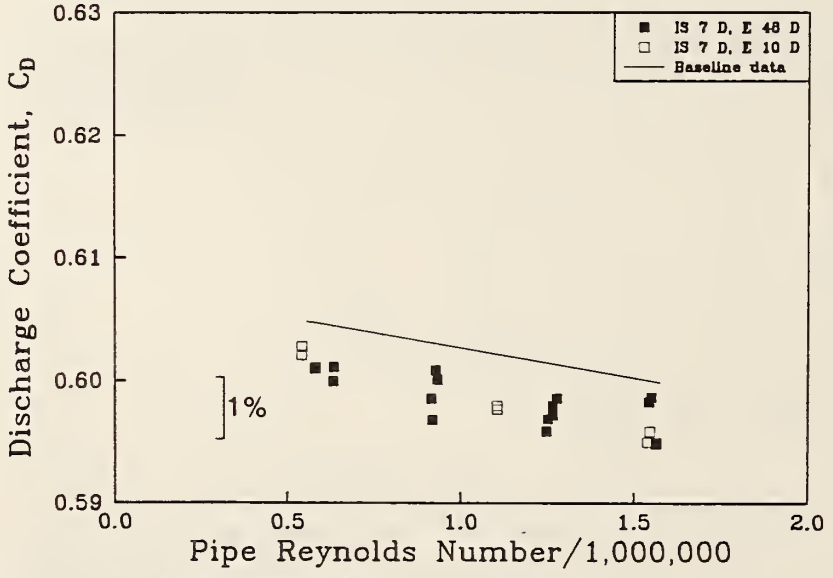


Figure 11. Discharge coefficients of a 0.55 beta ratio orifice meter in Configurations 5 and 6, 7 diameters from the in-line Sprenkle to the orifice plate and 10 or 48 diameters from the elbow to the in-line Sprenkle.

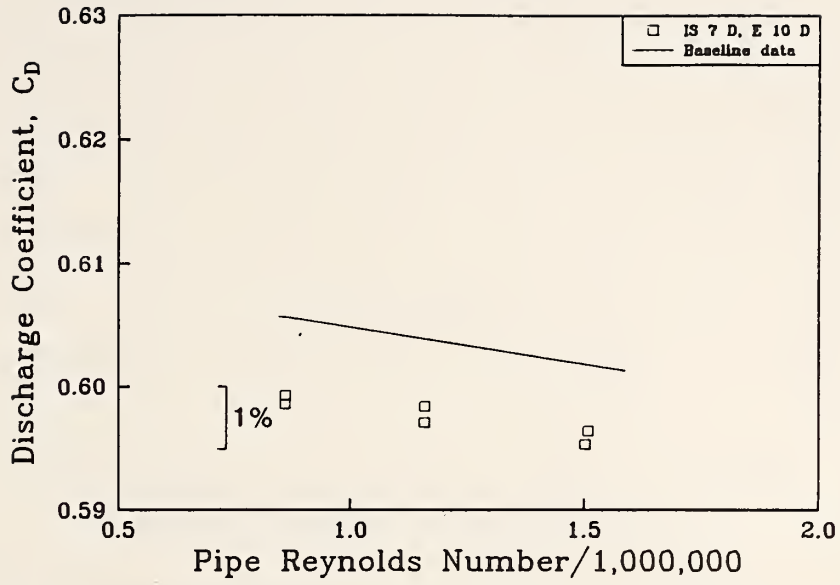


Figure 12. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 5, 7 diameters from the in-line Sprenkle to the orifice plate and 10 diameters from the elbow to the in-line Sprenkle.

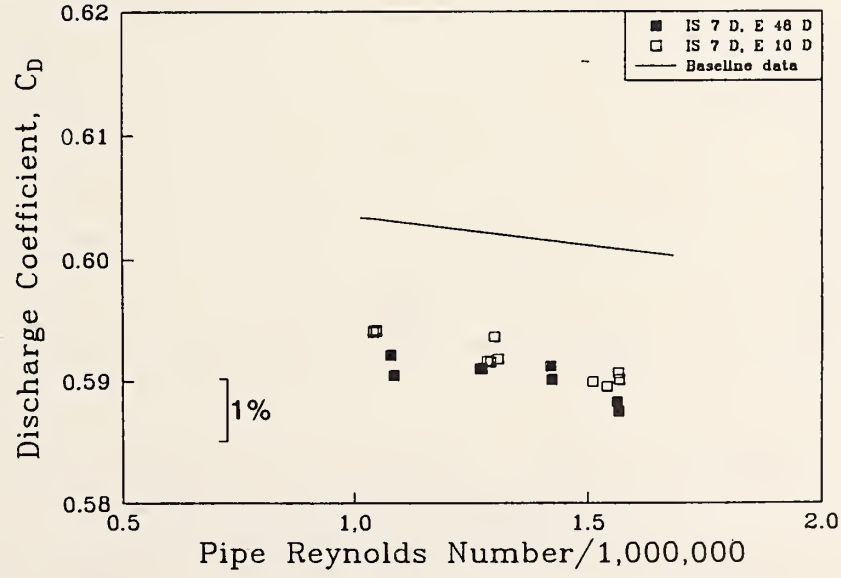


Figure 13. Discharge coefficients of a 0.73 beta ratio orifice meter in Configurations 5 and 6, 7 diameters from the in-line Sprenkle to the orifice plate and 10 or 48 diameters from the elbow to the in-line Sprenkle.

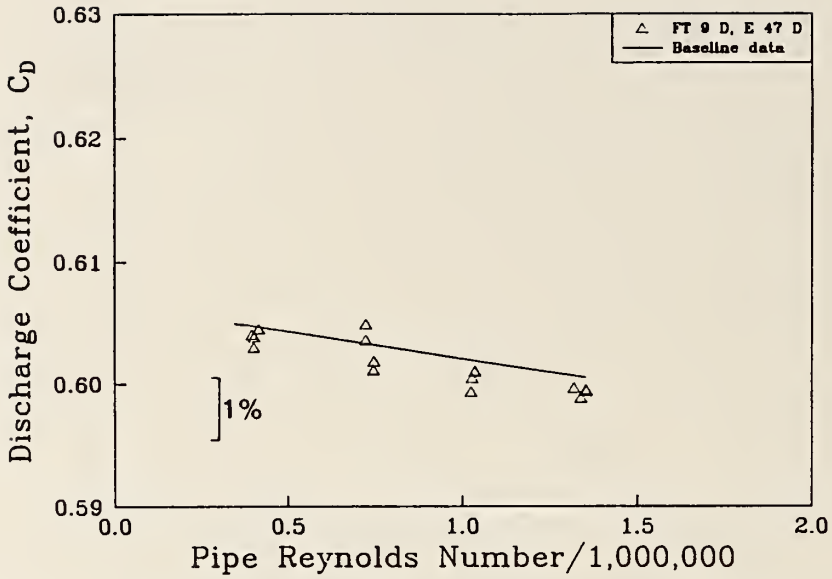


Figure 14. Discharge coefficients of a 0.43 beta ratio orifice meter in Configuration 7, 9 diameters from the flanged tube bundle to the orifice plate and 47 diameters from the elbow to the flanged tube bundle.

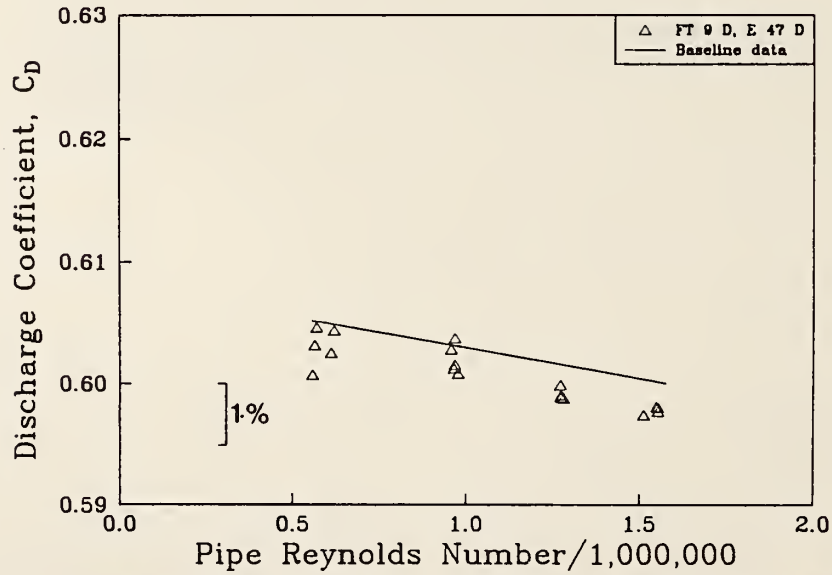


Figure 15. Discharge coefficients of a 0.55 beta ratio orifice meter in Configurations 7, 9 diameters from the flanged tube bundle to the orifice plate and 47 diameters from the elbow to the flanged tube bundle.

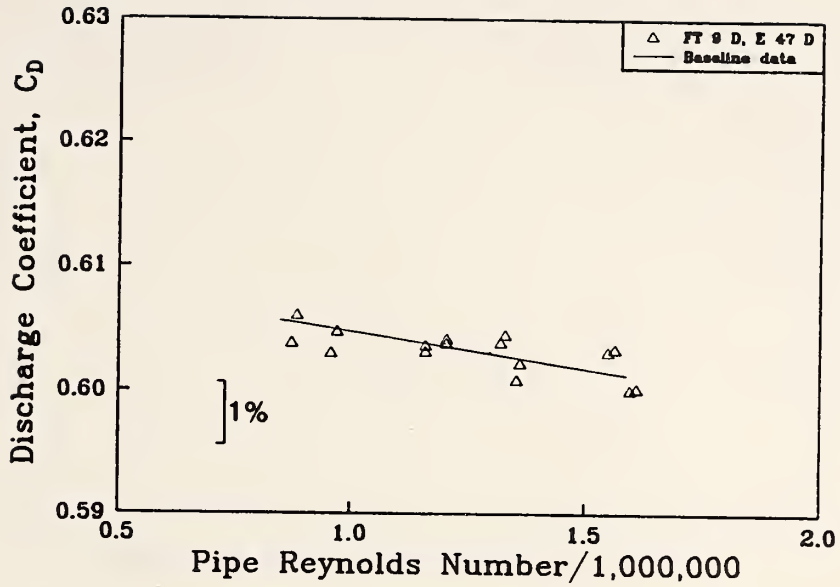


Figure 16. Discharge coefficients of a 0.67 beta ratio orifice meter in Configurations 7, 9 diameters from the flanged tube bundle to the orifice plate and 47 diameters from the elbow to the flanged tube bundle.

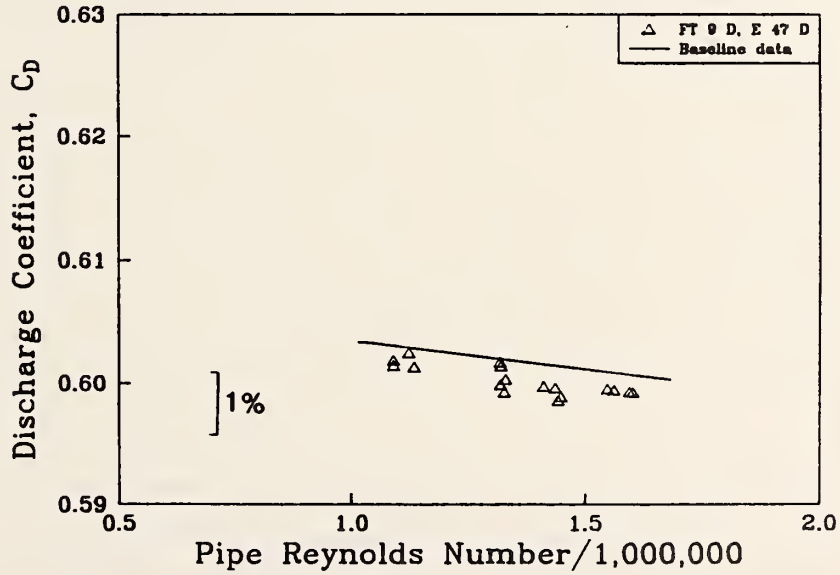


Figure 17. Discharge coefficients of a 0.73 beta ratio orifice meter in Configurations 7, 9 diameters from the flanged tube bundle to the orifice plate and 47 diameters from the elbow to the flanged tube bundle.

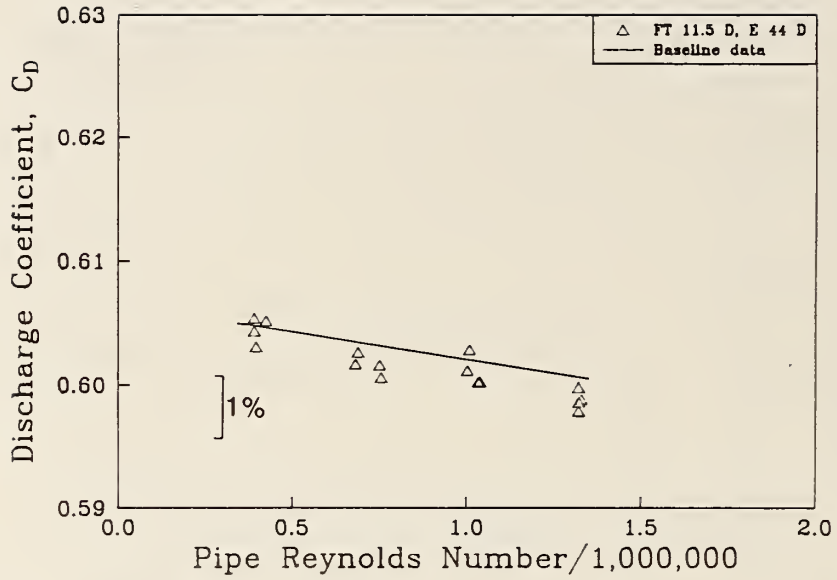


Figure 18. Discharge coefficients of a 0.43 beta ratio orifice meter in Configuration 8, 11.5 diameters from the flanged tube bundle to the orifice plate and 44 diameters from the elbow to the flanged tube bundle.

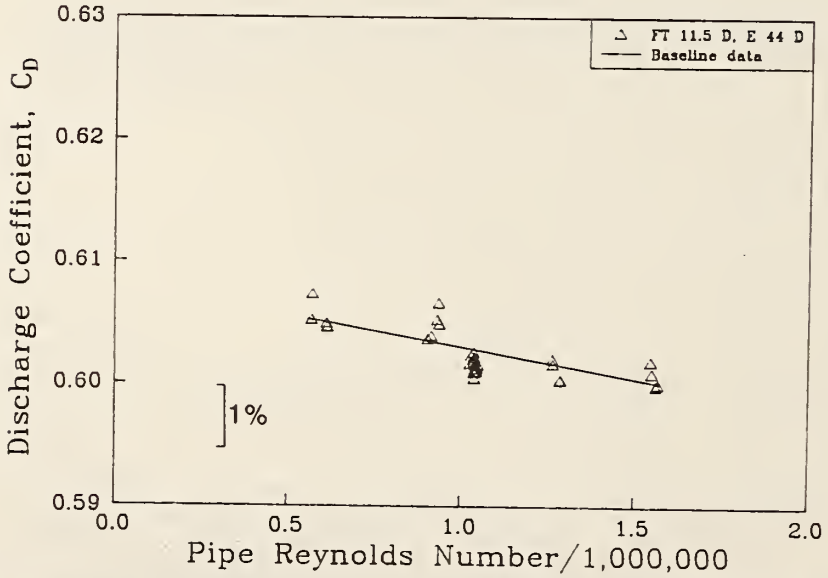


Figure 19. Discharge coefficients of a 0.55 beta ratio orifice meter in Configuration 8, 11.5 diameters from the flanged tube bundle to the orifice plate and 44 diameters from the elbow to the flanged tube bundle.

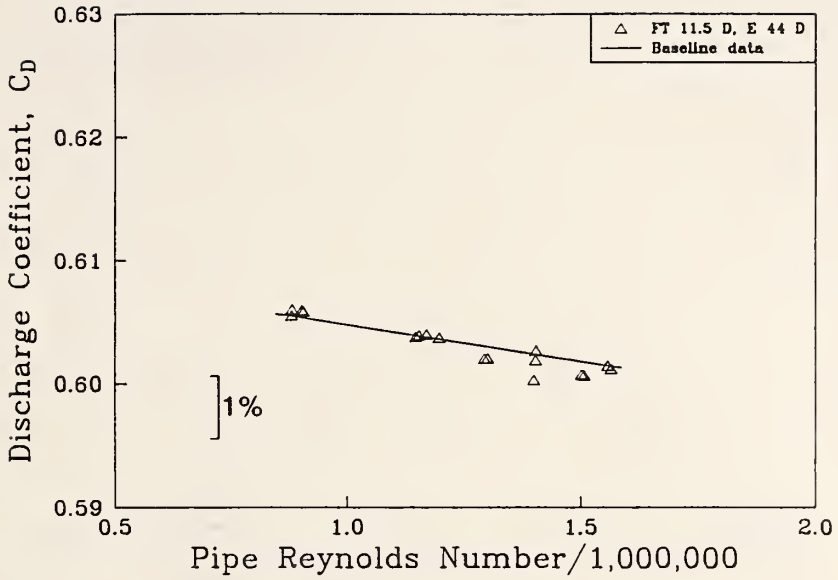


Figure 20. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 8, 11.5 diameters from the flanged tube bundle to the orifice plate and 44 diameters from the elbow to the flanged tube bundle.

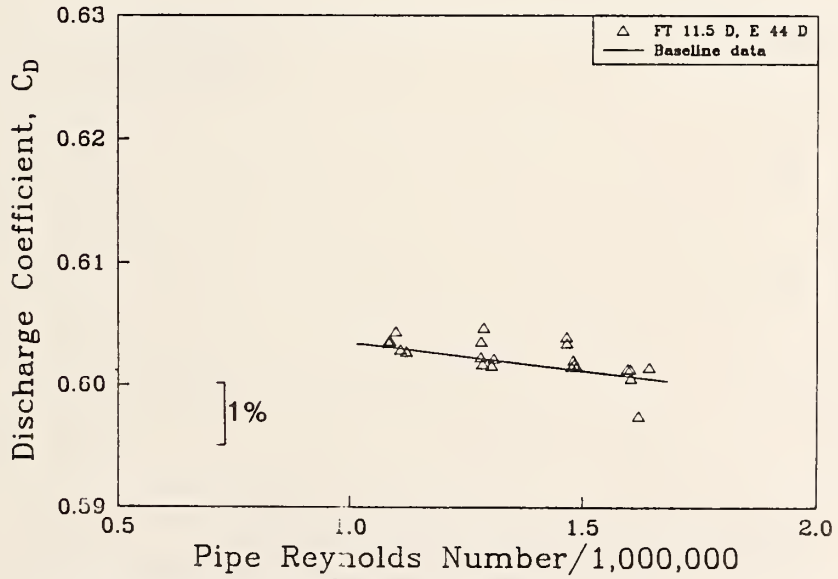


Figure 21. Discharge coefficients of a 0.73 beta ratio orifice meter in Configuration 8, 11.5 diameters from the flanged tube bundle to the orifice plate and 44 diameters from the elbow to the flanged tube bundle.

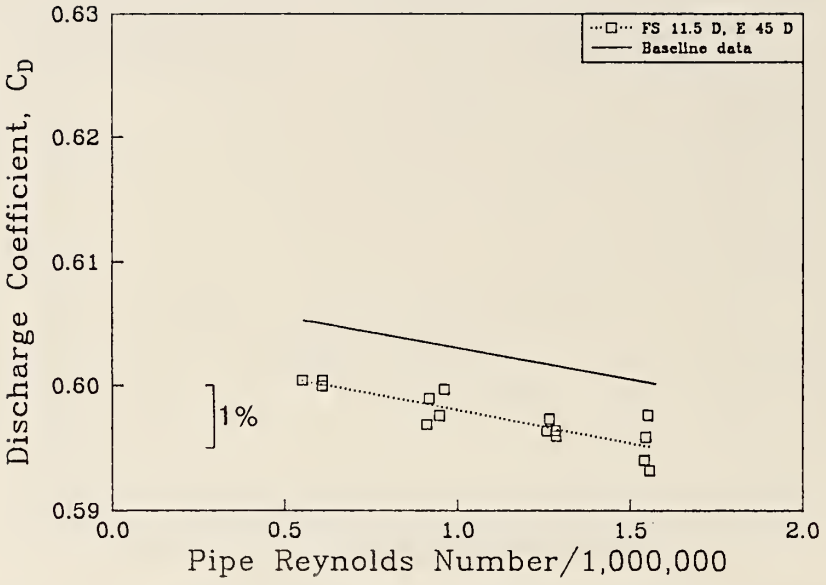


Figure 22. Discharge coefficients of a 0.55 beta ratio orifice meter in Configuration 9, 11.5 diameters from the flanged Sprenkle to the orifice plate and 45 diameters from the elbow to the flanged Sprenkle.

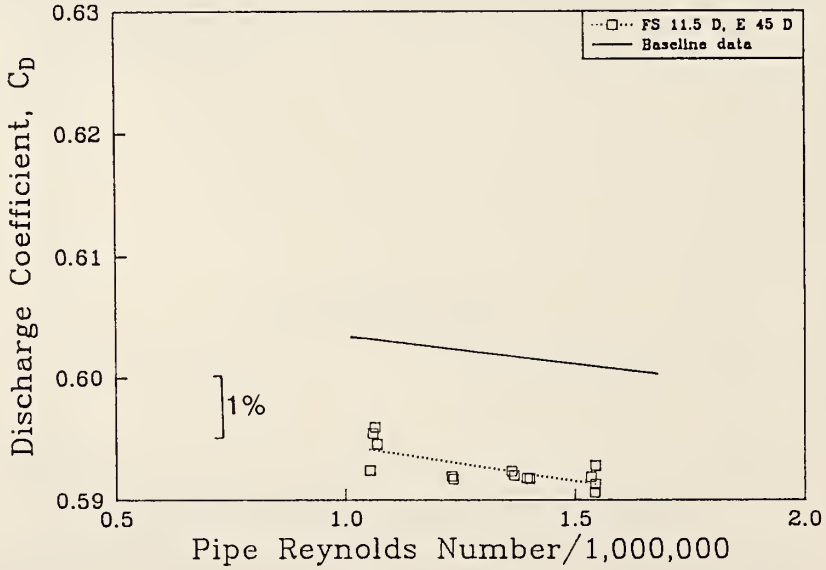


Figure 23. Discharge coefficient of a 0.73 beta ratio orifice meter in Configuration 9, 11.5 diameters from the flanged Sprenkle to the orifice plate and 45 diameters from the elbow to the flanged Sprenkle.

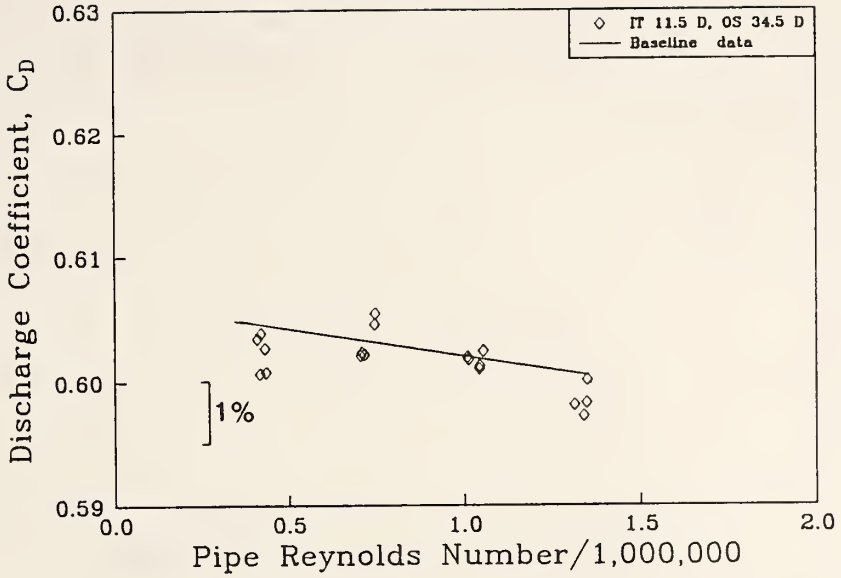


Figure 24. Discharge coefficient of a 0.43 beta ratio orifice meter in Configuration 10, 11.5 diameters from the in-line tube bundle installed in a 2 diameter spool piece and 34.5 diameters between the oversized Sprenkle and the in-line tube bundle.

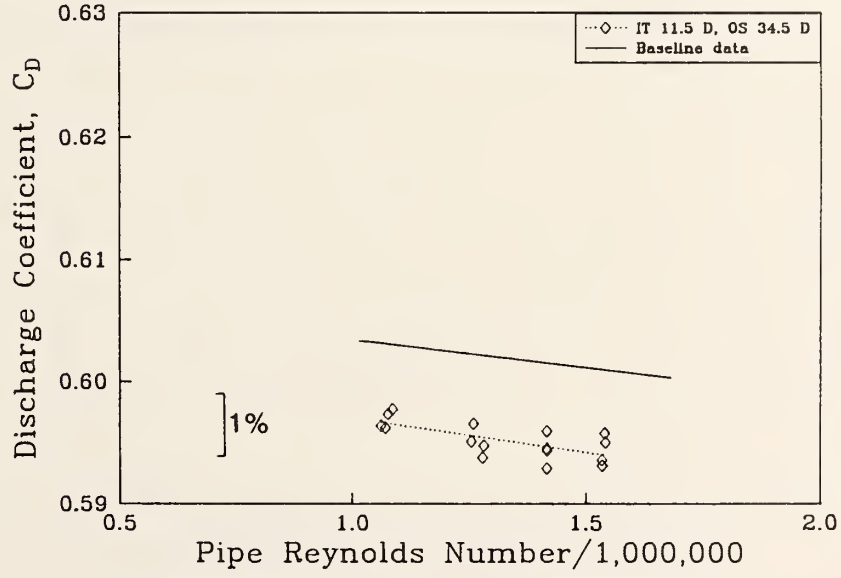


Figure 25. Discharge coefficient of a 0.73 beta ratio orifice meter in Configuration 10, 11.5 diameters from the in-line tube bundle installed in a 2 diameter spool piece and 34.5 diameters between the oversized Sprenkle and the in-line tube bundle.

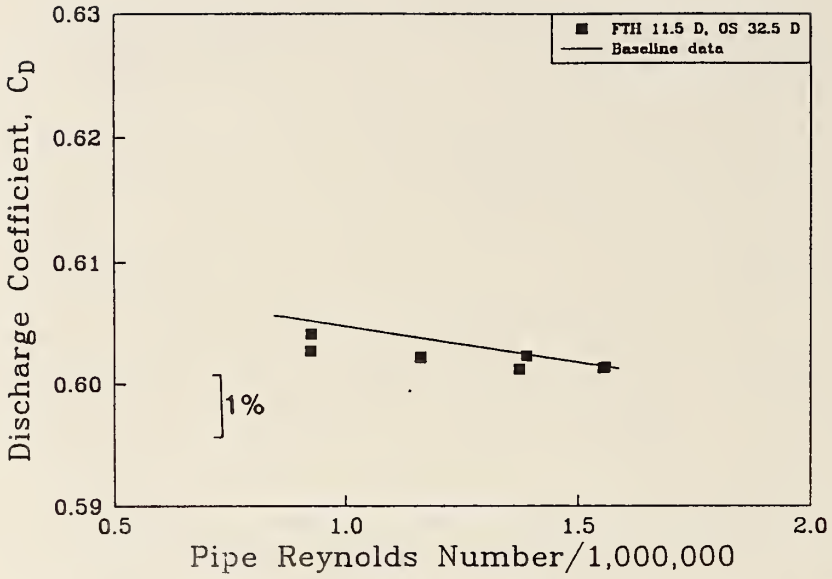


Figure 26. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 11, 11.5 diameters from the flanged tube bundle (hexagon pattern) to the orifice plate and 32.5 diameters from the elbow to the flanged tube bundle (hexagon pattern).

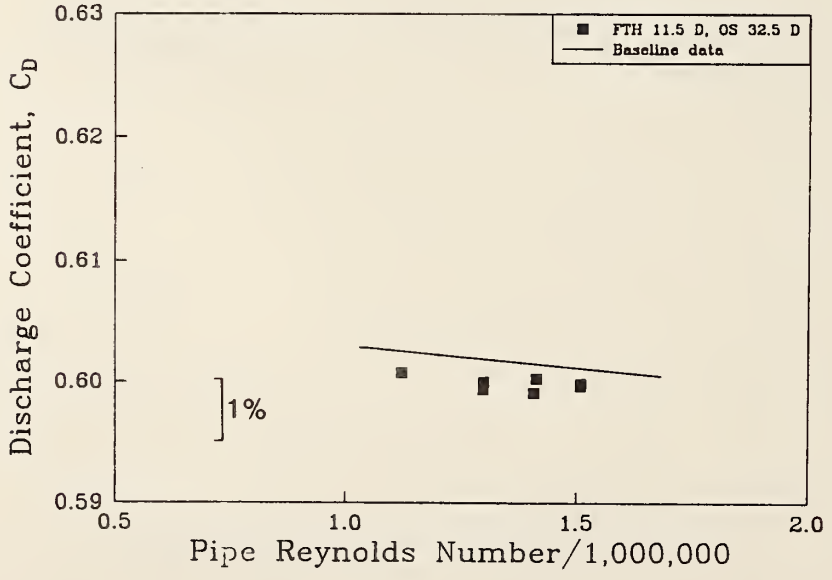


Figure 27. Discharge coefficients of a 0.73 beta ratio orifice meter in Configuration 11, 11.5 diameters from the flanged tube bundle (hexagon pattern) to the orifice plate and 32.5 diameters from the elbow to the flanged tube bundle (hexagon pattern)

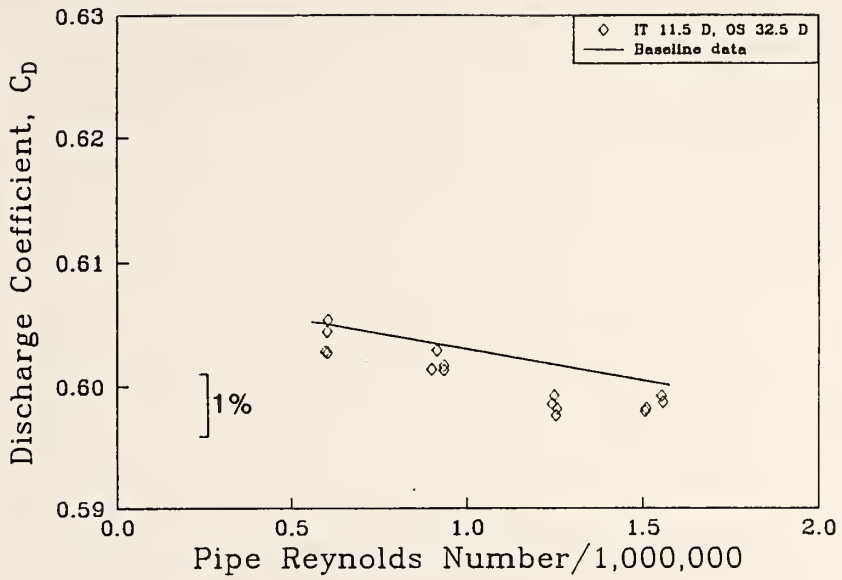


Figure 28. Discharge coefficients of a 0.55 beta ratio orifice meter in Configuration 11, 11.5 diameters from the in-line tube bundle to the orifice plate and 32.5 diameters from the oversized Sprenkle to the in-line tube bundle.

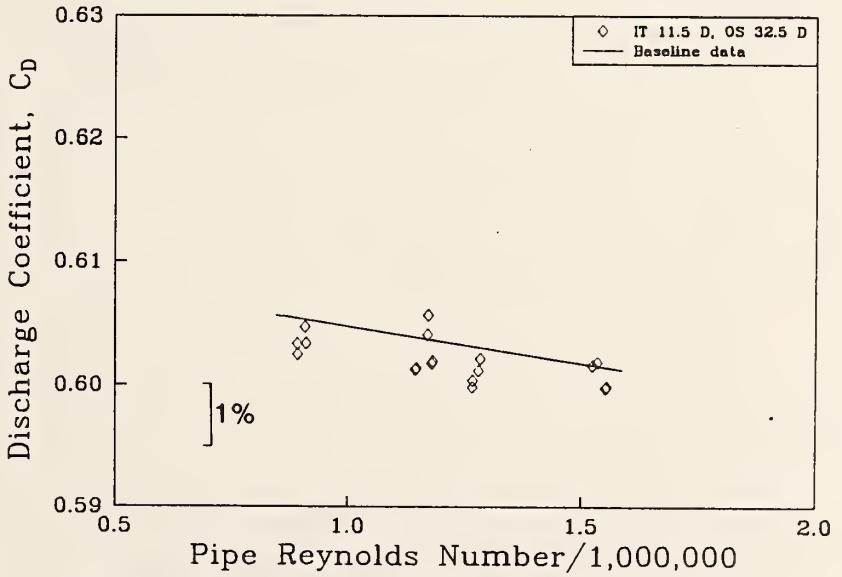


Figure 29. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 11, 11.5 diameters from the in-line tube bundle to the orifice plate and 32.5 diameters from the oversized Sprenkle to the in-line tube bundle.

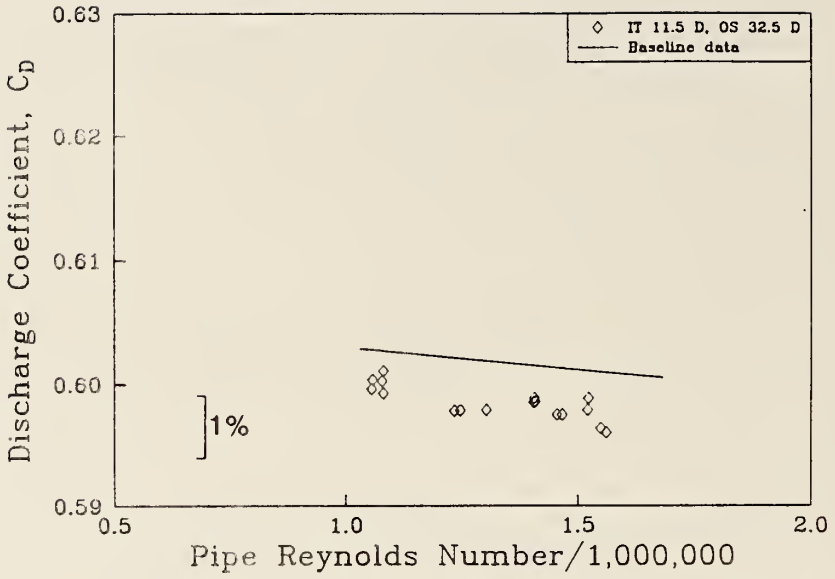


Figure 30. Discharge coefficients of a 0.73 beta ratio orifice meter in Configuration 11, 11.5 diameters from the in-line tube bundle to the orifice plate and 32.5 diameters from the oversized Sprenkle to the in-line tube bundle.

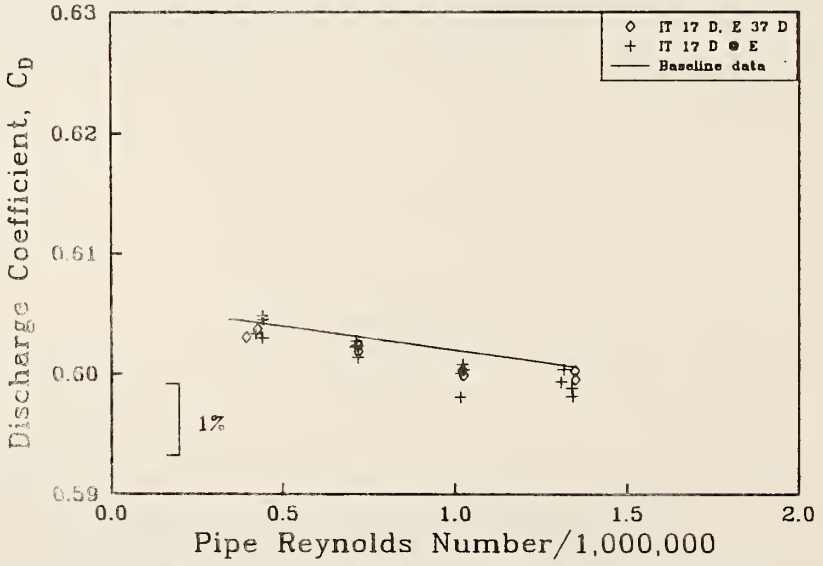


Figure 31. Discharge coefficients of a 0.43 beta ratio orifice meter in Configuration 13 and 14, 17 diameters from an in-line tube bundle to the orifice plate.

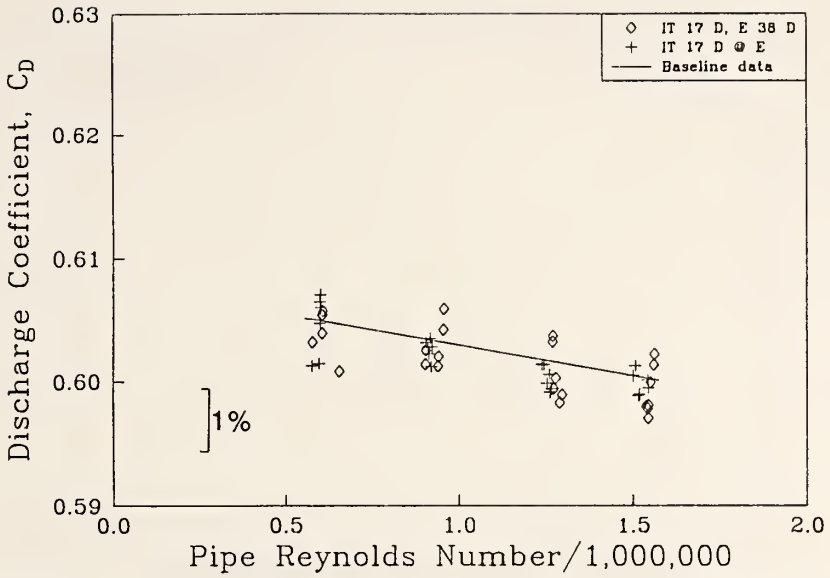


Figure 32. Discharge coefficients of a 0.55 beta ratio orifice meter in Configuration 13 and 14, 17 diameters from the in-line tube bundle to the orifice plate.

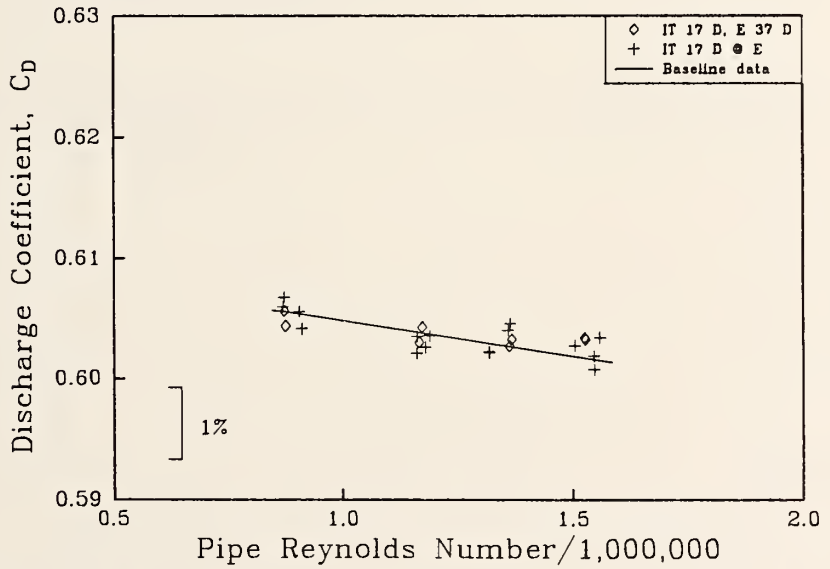


Figure 33. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 13 and 14, 17 diameters from the in-line tube bundle to the orifice plate.

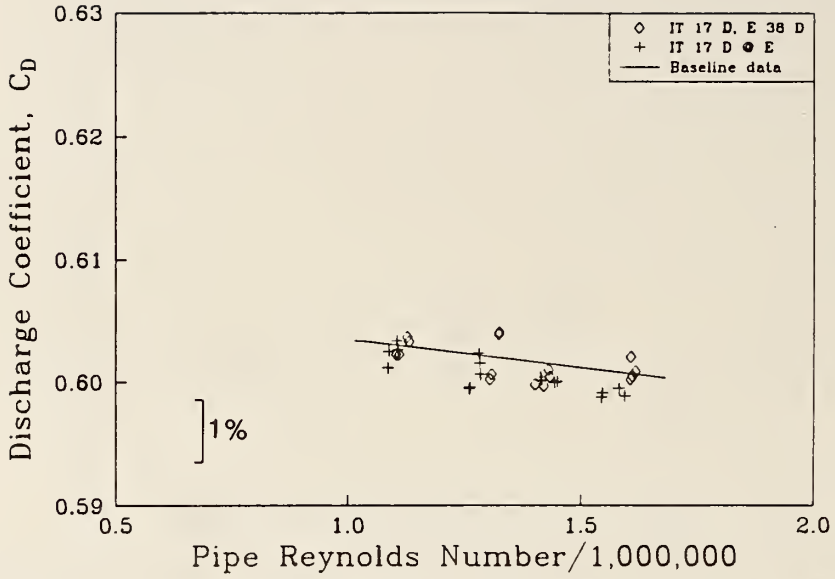


Figure 34. Discharge coefficients of a 0.73 beta ratio orifice meter in Configuration 13 and 14, 17 diameters from the in-line tube bundle to the orifice plate.

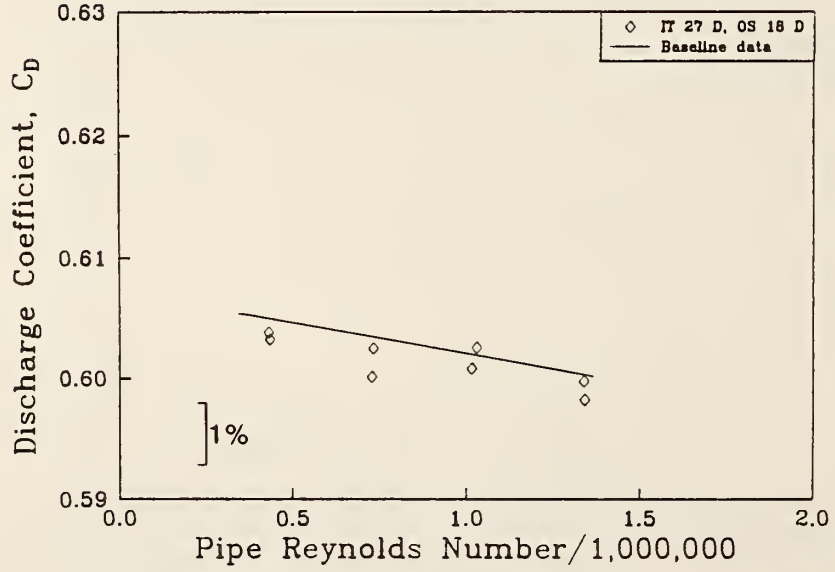


Figure 35. Discharge coefficients of a 0.43 beta ratio orifice meter in Configuration 14, 27 diameters from an in-line tube bundle to the orifice plate and 17 diameters from the oversized Sprenkle to the in-line tube bundle.

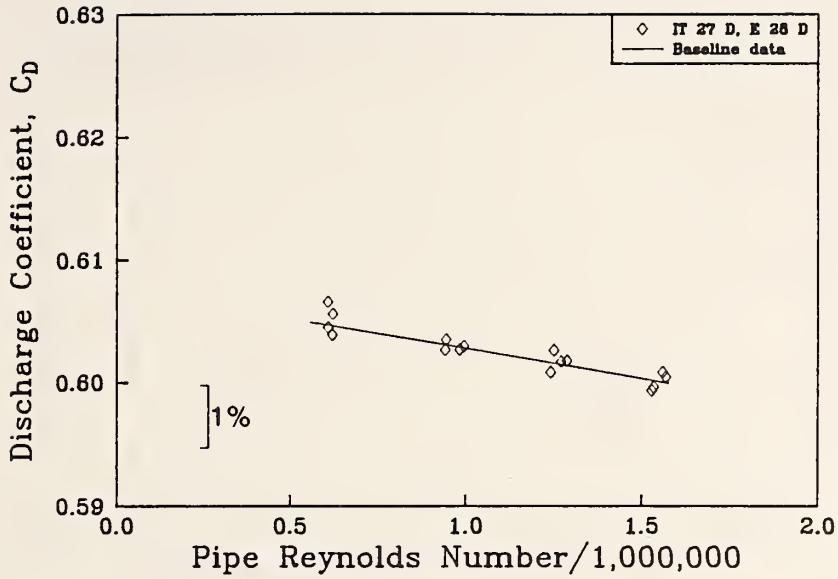


Figure 36. Discharge coefficients of a 0.55 beta ratio orifice meter in Configuration 15, 27 diameters from the in-line tube bundle to the orifice plate and 28 diameters from the elbow to the in-line tube bundle.

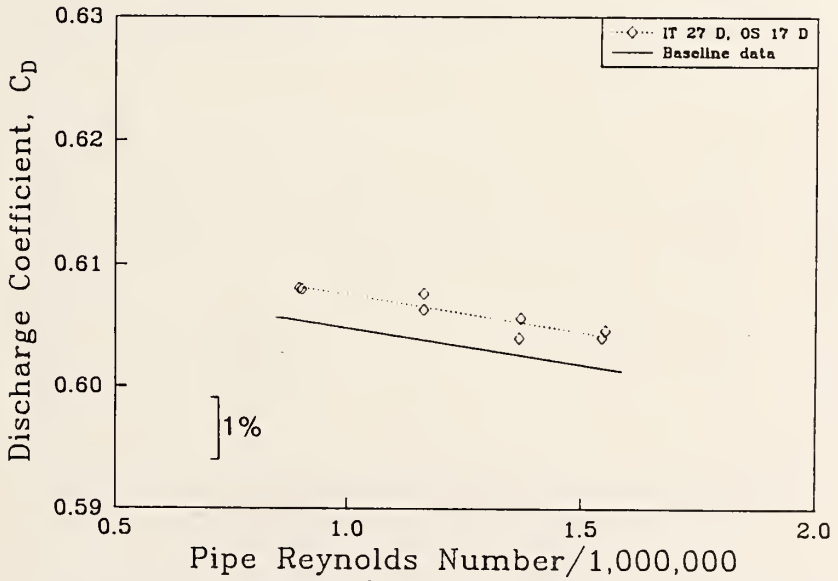


Figure 37. Discharge coefficients of a 0.67 beta ratio orifice meter in Configuration 14, 27 diameters from the in-line tube bundle to the orifice plate and 17 diameters from the oversized Sprenkle to the in-line tube bundle.

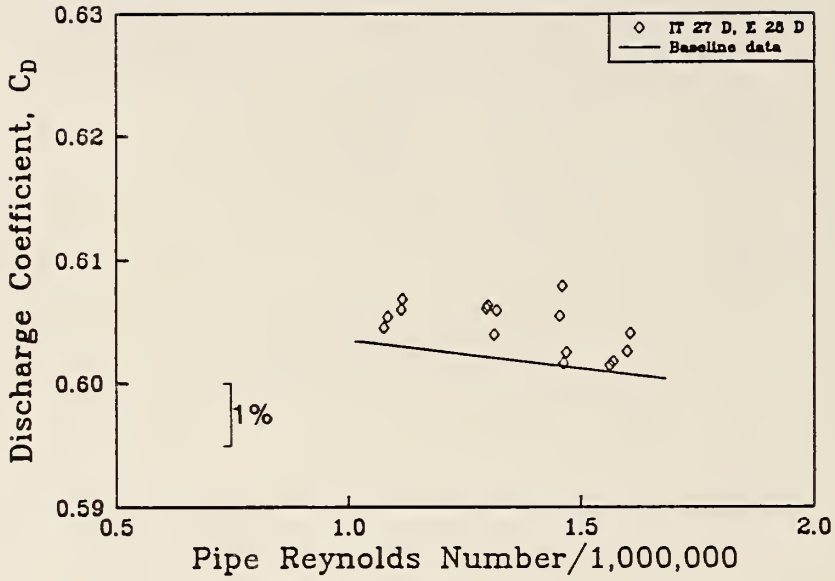


Figure 38. Discharge coefficients of a 0.73 beta ratio orifice meter in Configuration 15, 27 diameters from the in-line tube bundle to the orifice plate and 28 diameters from the elbow to the in-line tube bundle.

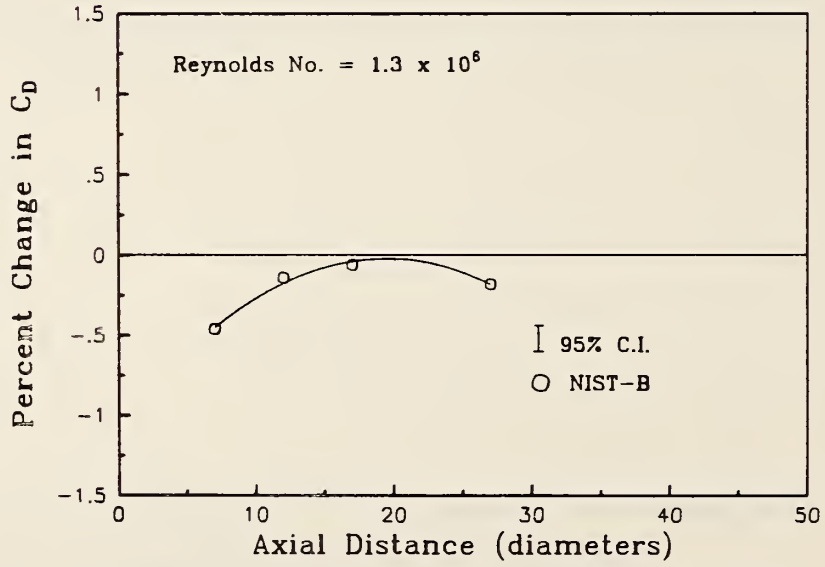


Figure 39. Percent change in the discharge coefficient as a function of the axial distance for the 0.43 beta ratio plate ($Re_D = 1.3x10^6$).

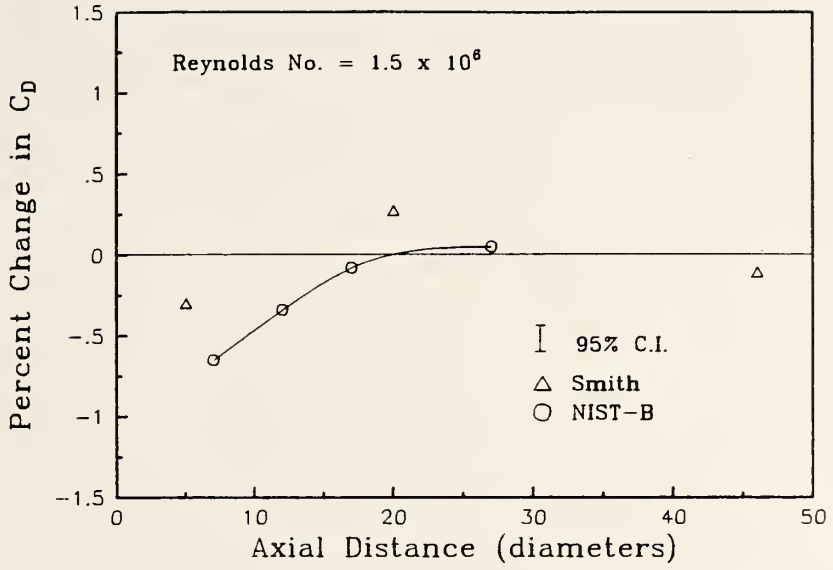


Figure 40. Percent change in the discharge coefficient as a function of the axial distance for the 0.55 beta ratio plate ($Re_D = 1.5x10^6$).

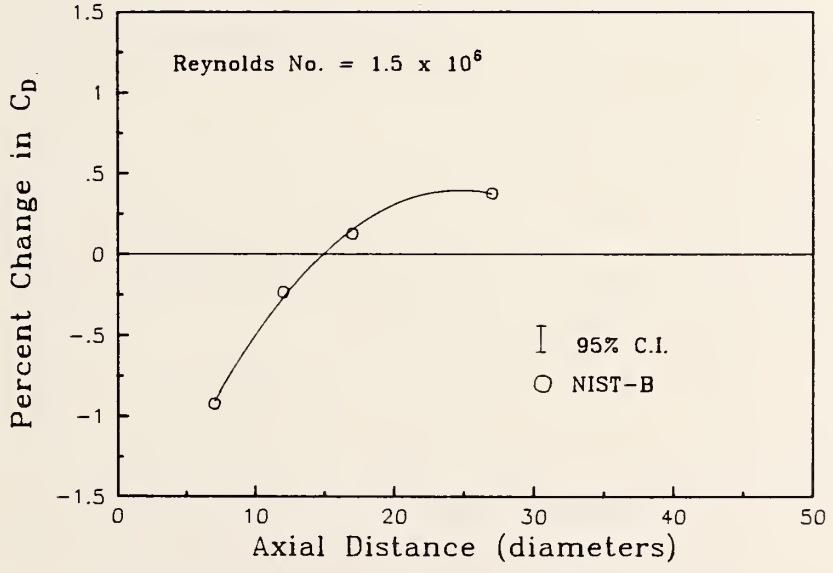


Figure 41. Percent change in the discharge coefficient as a function of the axial distance for the 0.67 beta ratio plate ($Re_D = 1.5x10^6$).

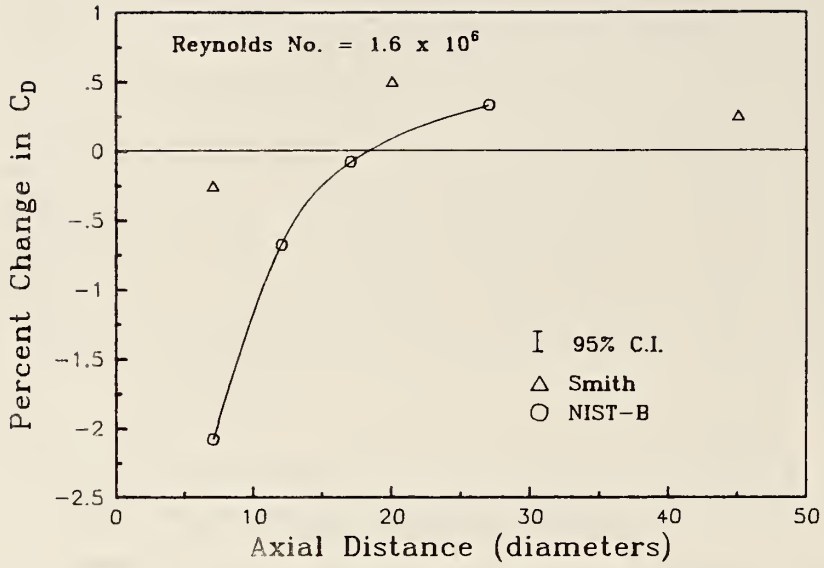


Figure 42. Percent change in the discharge coefficient as a function of the axial distance for the 0.73 beta ratio plate ($Re_D = 1.6x10^6$).

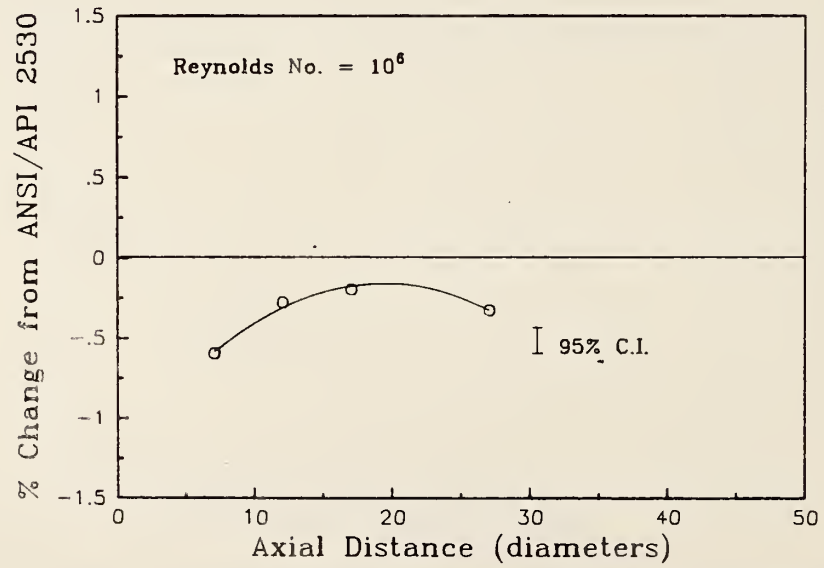


Figure 43. Percent change in the discharge coefficient from ANSI/API 2530 as a function of the axial distance for the 0.43 beta ratio plate ($Re_D = 10^6$).

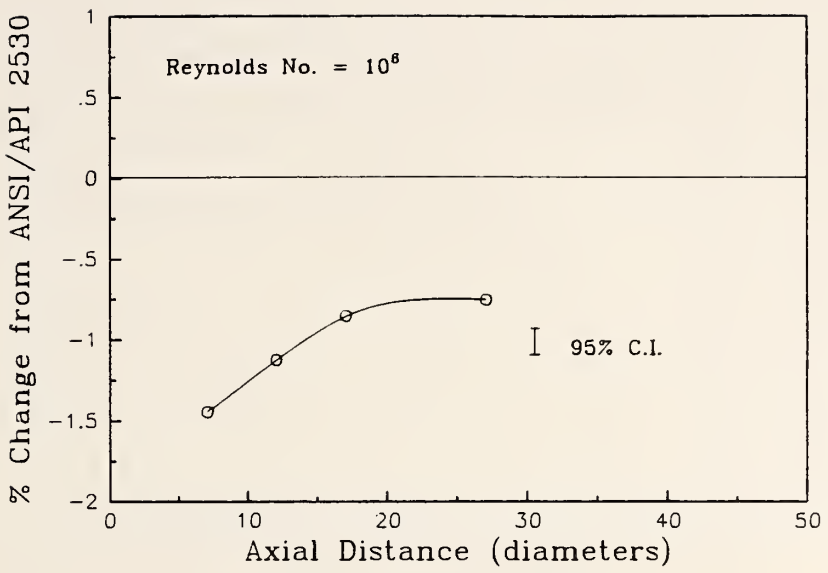


Figure 44. Percent change in the discharge coefficient from ANSI/API 2530 as a function of the axial distance for the 0.55 beta ratio plate ($Re_D = 10^6$).

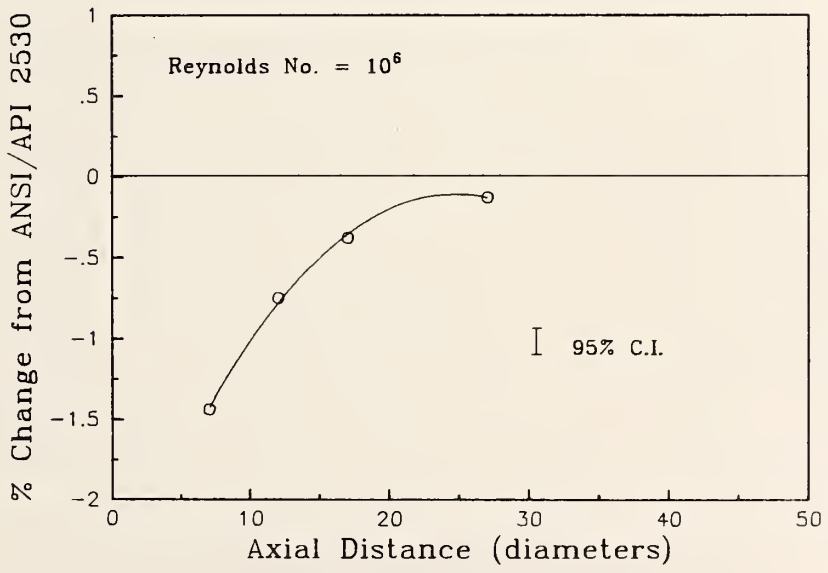


Figure 45. Percent change in the discharge coefficient from ANSI/API 2530 as a function of the axial distance for the 0.67 beta ratio plate ($Re_D = 10^6$).

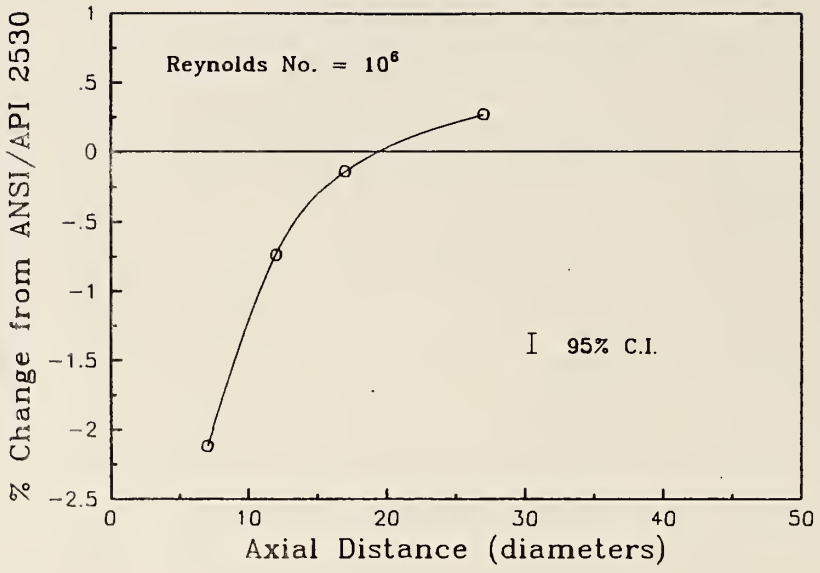


Figure 46. Percent change in the discharge coefficient from ANSI/API 2530 as a function of the axial distance for the 0.73 beta ratio plate ($Re_D = 10^6$).

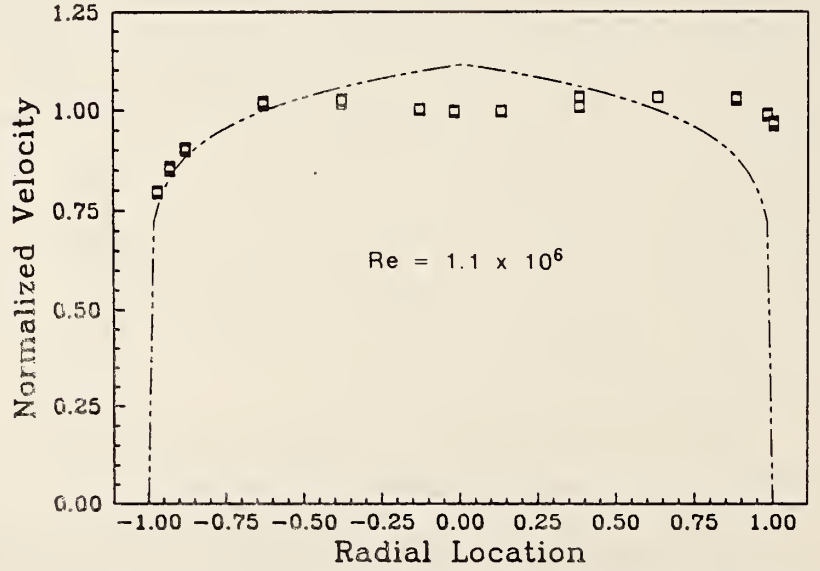


Figure 47. Normalized velocity profile 7 pipe diameters downstream of an in-line tube bundle flow conditioner. Dashed line represents the fully developed turbulent velocity profile calculated from equation 1.

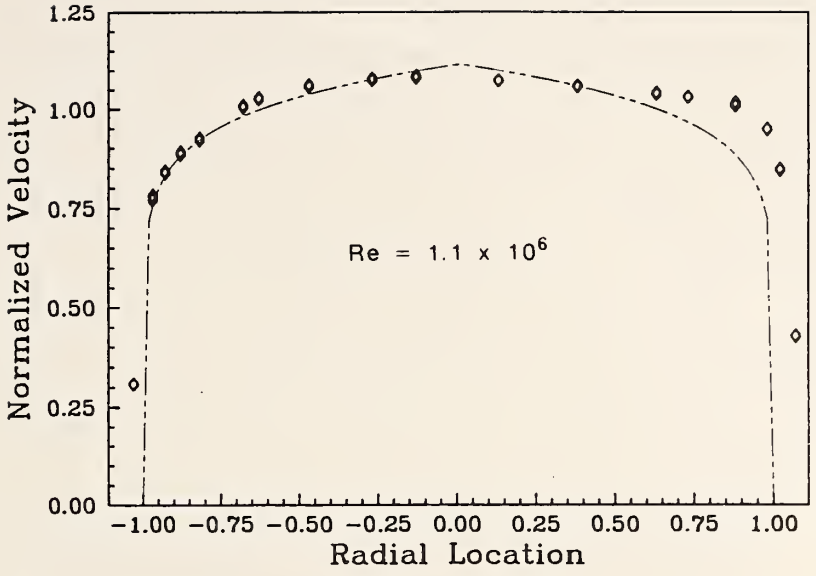


Figure 48. Normalized velocity profile 11.5 pipe diameters downstream of a flanged tube bundle flow conditioner. Dashed line represents the fully developed turbulent velocity profile calculated from equation 1.

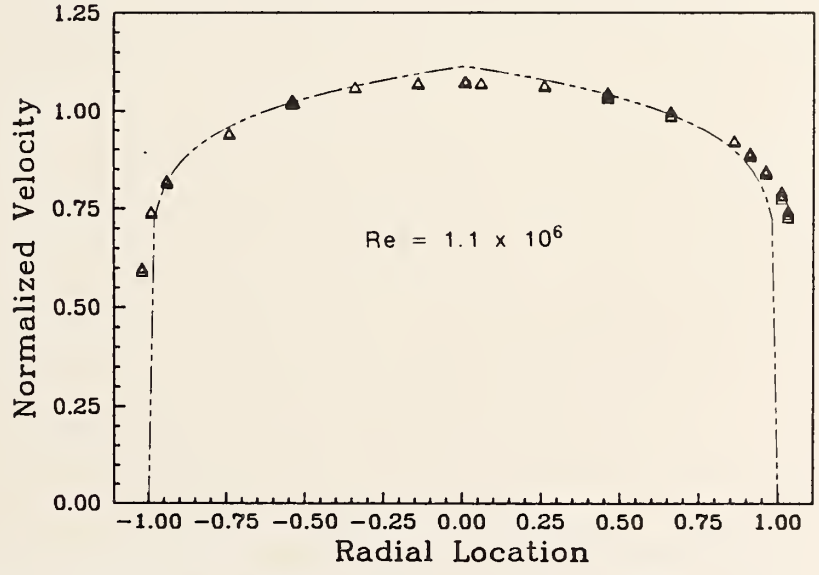


Figure 49. Normalized velocity profile 27 pipe diameters downstream of an in-line tube bundle flow conditioner. Dashed line represents the fully developed turbulent velocity profile calculated from equation 1.

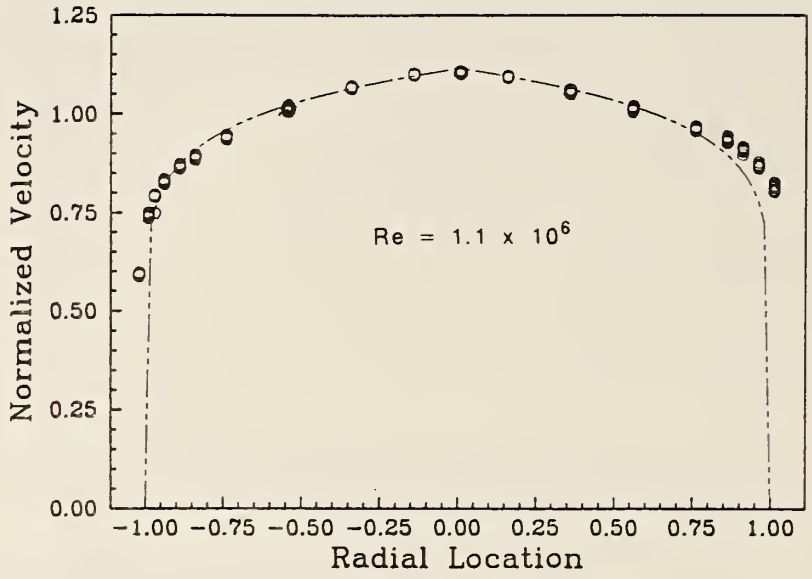


Figure 50. Normalized velocity profile 47 pipe diameters downstream of an oversized Sprenkle flow conditioner. Dashed line represents the fully developed turbulent velocity profile calculated from equation 1.

APPENDIX A

Flow Conditioner Measurements and Illustrations

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Table A.1. Tube Bundle Flow Conditioner Measurements

	Flanged Round Pattern	In-line Hexagon Pattern	In-line Round Pattern
Surface finish inside of tubes (μm(μin))	3.9(155)	0.76(30)	0.64(25)
Tube wall thickness (cm(in))	0.127(0.050)	0.127(0.050)	0.165(0.065)
Tube inside diameter (cm(in))	1.80(0.710)	1.65(0.650)	1.56(0.615)
Maximum diameter of tubes (cm(in))	10.109(3.980)	9.589(3.775)	9.779(3.815)

Flanged tube bundle with round pattern had no filling between any of the tubes.

Flanged tube bundle with hexagon pattern had very small holes between tubes.

In-line tube bundle with round pattern had half of the holes filled. The large holes were open; the small ones are closed.

Table A.2 Sprenkle Flow Conditioner Measurements

	In-line Sprenkle	Flanged Sprenkle
Diameter (cm(in))	10.145(3.994)	10.165(4.002)
Plate thickness (cm(in))	0.970(0.382)	0.983(0.387)
Number of holes	63	63
Average hole diameter (cm(in))	0.610(0.240)	0.617(0.243)
Distance between plate 1 and 2 (cm(in))	8.666(3.412)	8.529(3.358)
Distance between plate 2 and 3 (cm(in))	8.611(3.390)	8.733(3.438)
Average rod diameter (cm(in))	1.918(0.755)	1.951(0.768)

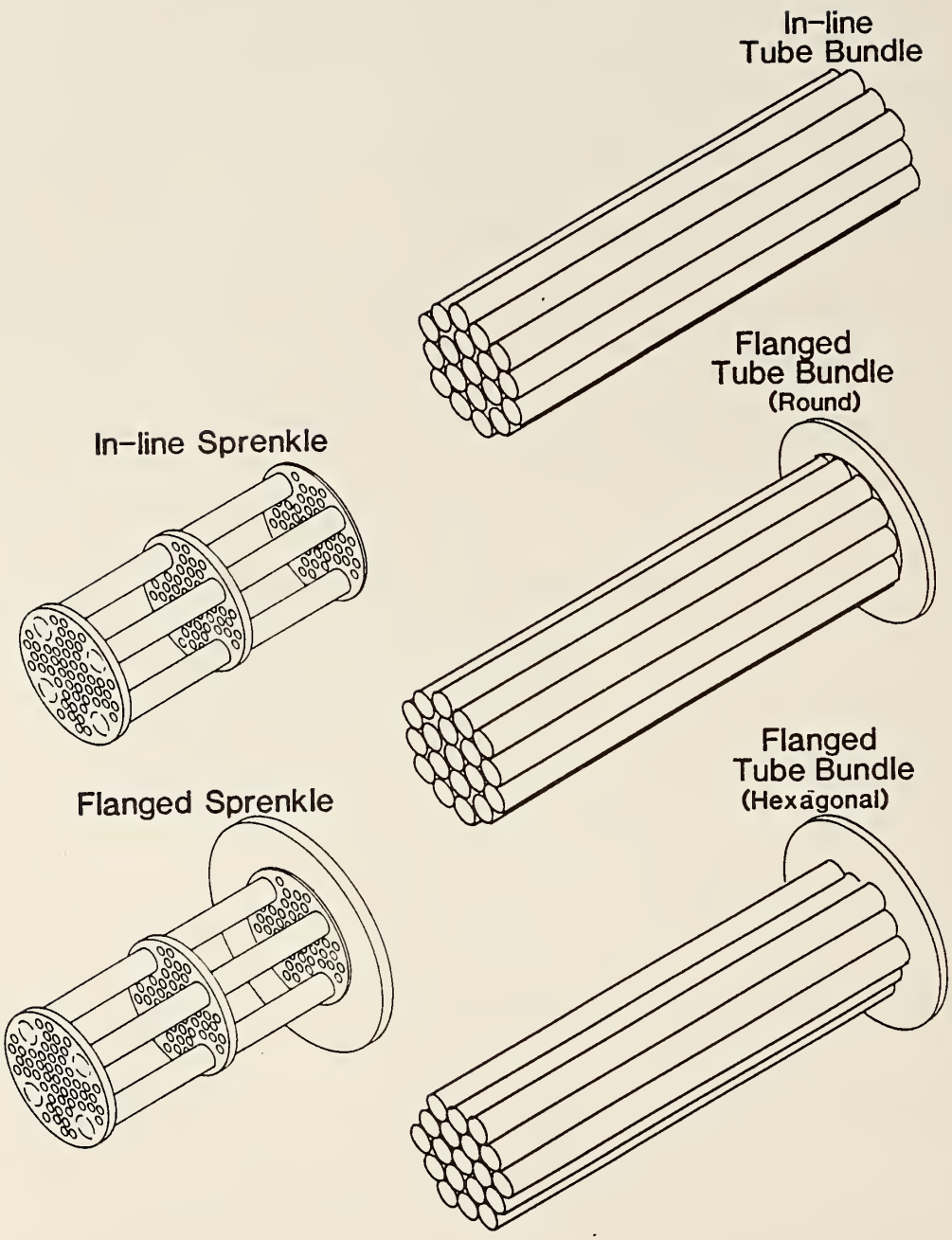

Figure A.1. Illustration of flow conditioners.

APPENDIX B

Measured and Calculated Quantities in SI Units for the Flow Conditioner Location Study

CONVERSION FACTORS

To convert from	To	Multiply By
psi	MPa	6.8948×10^{-3}
in. of water (60°F)	kPa	0.24884
inch	cm	2.54
inch	mm	25.4
μin	μm	0.0254
°R	K	0.55556
lb/s	kg/s	0.45359

List of Tables

Table B.1 **Measured and calculated quantities for the 0.43 beta ratio plate with the oversized Sprenkle 47 pipe diameters upstream of the orifice plate (Configuration 1).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43071886- 1	4.0736	290.36	47.59	3.129	0.5219	351100	0.6061	0.6062
43071886- 3	3.7245	288.96	43.74	49.425	1.9767	1339900	0.6007	0.6024
43071886- 4	3.7241	288.81	43.76	48.820	1.9613	1330000	0.5997	0.6013
43071886- 5	3.8892	289.26	45.63	19.313	1.2599	851800	0.6008	0.6015
43071886- 6	3.8880	289.29	45.60	19.688	1.2732	860700	0.6015	0.6021
43072986- 1	3.7847	288.36	44.55	47.704	1.9585	1328500	0.6004	0.6020
43072986- 2	3.7842	288.36	44.54	47.476	1.9528	1324700	0.6001	0.6017
43072986- 3	4.0664	289.91	47.59	3.003	0.5106	343900	0.6054	0.6055
43072986- 4	4.0964	290.29	47.87	2.991	0.5116	344200	0.6061	0.6062
43072986- 5	3.9354	288.76	46.26	19.243	1.2700	859100	0.6026	0.6032
43072986- 6	3.9356	288.72	46.27	19.081	1.2650	855900	0.6028	0.6034
43080186- 1	3.9650	288.56	46.64	18.392	1.2472	843900	0.6029	0.6035
43080186- 2	3.9650	288.41	46.67	18.363	1.2459	843200	0.6026	0.6032
43080186- 4	4.1115	289.52	48.19	3.473	0.5511	371400	0.6039	0.6040
43080186- 5	3.8213	288.32	44.99	48.545	1.9913	1350400	0.6022	0.6038
43080186- 6	3.8216	288.14	45.02	48.333	1.9831	1345400	0.6008	0.6024
43012188- 1	4.0198	288.63	47.27	12.547	1.0331	698400	0.6008	0.6011
43012188- 2	4.0089	288.74	47.13	12.556	1.0362	700400	0.6032	0.6036
43012188- 3	4.0151	288.67	47.21	12.551	1.0363	700500	0.6029	0.6033
43012188- 4	3.8663	288.09	45.56	28.419	1.5275	1035800	0.6006	0.6015
43012188- 5	3.8710	288.13	45.61	28.007	1.5167	1028300	0.6004	0.6013
43012188- 6	4.1118	289.29	48.24	4.350	0.6187	417100	0.6053	0.6054
43012188- 7	4.1343	289.33	48.50	4.756	0.6498	437900	0.6062	0.6064
43012188- 8	3.7778	287.72	44.58	48.528	1.9796	1345000	0.6015	0.6031
43012188- 9	3.7688	287.60	44.49	49.010	1.9860	1349900	0.6010	0.6027
43020488- 1	3.7767	288.44	44.44	49.327	1.9922	1351200	0.6012	0.6029
43020488- 2	3.7781	288.36	44.47	49.196	1.9863	1347400	0.6001	0.6018
43020488- 3	4.0975	289.78	47.98	4.333	0.6116	411900	0.6010	0.6011
43020488- 4	4.1165	289.93	48.18	4.879	0.6540	440200	0.6044	0.6045
43020488- 5	3.9357	288.84	46.25	27.367	1.5181	1026700	0.6038	0.6047
43020488- 6	3.9137	288.79	46.00	28.043	1.5321	1036600	0.6036	0.6045
43020488- 7	4.0432	289.34	47.42	13.227	1.0670	719900	0.6033	0.6037
43020488- 8	4.0445	289.29	47.45	13.373	1.0700	722000	0.6015	0.6019

Table B.2 **Measured and calculated quantities for the 0.55 beta ratio plate with the oversized Sprenkle 47 pipe diameters upstream of the orifice plate (Configuration 1).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44062587- 1	3.8646	289.27	45.33	15.000	1.8803	1271500	0.5987	0.5992
44062587- 2	3.8704	288.62	45.51	14.888	1.8815	1274300	0.6002	0.6007
44062587- 3	4.0973	287.03	48.49	2.741	0.8355	566500	0.6023	0.6024
44062587- 4	4.0938	288.61	48.15	2.666	0.8224	555500	0.6032	0.6033
44062587- 5	3.7055	291.18	43.15	23.988	2.3231	1566700	0.5992	0.6000
44062587- 6	3.7143	287.31	43.89	23.466	2.3147	1575500	0.5987	0.5994
44062587- 7	3.9626	286.56	46.97	7.650	1.3738	934000	0.6021	0.6023
44062587- 8	3.9759	288.10	46.85	7.735	1.3772	932700	0.6010	0.6012
44012188- 1	4.0718	288.75	47.87	2.990	0.8722	589100	0.6059	0.6060
44012188- 2	4.0443	288.86	47.52	2.979	0.8687	586700	0.6067	0.6068
44012188- 3	3.9390	288.23	46.39	7.254	1.3360	904800	0.6050	0.6052
44012188- 4	3.9179	288.24	46.14	7.147	1.3219	895500	0.6047	0.6050
44012188- 5	3.6833	287.12	43.55	22.292	2.2586	1538500	0.6017	0.6024
44012188- 6	3.6774	286.77	43.54	22.067	2.2442	1530100	0.6010	0.6017
44012188- 7	3.8286	287.56	45.20	15.640	1.9238	1306700	0.6008	0.6013
44012188- 8	3.7995	287.28	44.91	15.655	1.9182	1304300	0.6008	0.6013
44012888- 1	4.0936	288.42	48.18	2.669	0.8262	558300	0.6054	0.6055
44012888- 2	4.0993	288.43	48.25	2.731	0.8366	565200	0.6057	0.6057
44012888- 3	3.7182	288.45	43.75	22.382	2.2668	1538500	0.6013	0.6020
44012888- 4	3.7092	288.53	43.63	22.050	2.2472	1525100	0.6014	0.6021
44012888- 5	3.9359	289.13	46.20	8.083	1.4097	952700	0.6060	0.6062
44012888- 6	3.9378	289.24	46.20	8.153	1.4130	954700	0.6048	0.6051
44012888- 7	3.9379	289.34	46.18	8.131	1.4114	953300	0.6050	0.6053
44012888- 8	3.8460	288.74	45.20	14.248	1.8394	1245600	0.6019	0.6023
44012888- 9	3.8506	289.11	45.20	14.163	1.8322	1239600	0.6014	0.6018

Table B.3 Measured and calculated quantities for the 0.67 beta ratio plate with the oversized Sprenkle 47 pipe diameters upstream of the orifice plate (Configuration 1).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45062587- 1	3.8891	287.74	45.89	6.715	2.0405	1384600	0.6046	0.6047
45062587- 2	3.8923	288.16	45.85	6.703	2.0366	1380400	0.6042	0.6044
45062587- 3	4.0134	288.41	47.24	2.808	1.3411	907200	0.6058	0.6058
45062587- 4	4.0072	288.39	47.17	2.794	1.3419	907800	0.6080	0.6081
45062587- 5	3.7444	287.27	44.25	9.137	2.3317	1586700	0.6030	0.6033
45062587- 6	3.7552	288.04	44.25	9.195	2.3373	1587300	0.6026	0.6028
45062587- 7	3.9079	287.63	46.13	5.185	1.7969	1219300	0.6043	0.6045
45062587- 8	3.8997	287.81	46.00	5.206	1.7941	1217000	0.6030	0.6032
45012788- 1	3.8702	288.73	45.49	5.107	1.7640	1194300	0.6020	0.6021
45012788- 2	3.8662	288.78	45.44	5.080	1.7590	1190800	0.6022	0.6024
45012788- 3	3.6855	288.28	43.39	8.520	2.2197	1507700	0.6004	0.6006
45012788- 4	3.6828	287.62	43.47	8.453	2.2140	1506300	0.6007	0.6009
45012788- 5	3.8279	288.51	45.03	6.280	1.9430	1316800	0.6009	0.6011
45012788- 6	3.8167	288.42	44.91	6.290	1.9456	1319000	0.6021	0.6022
45012788- 7	3.9297	289.18	46.12	2.548	1.2592	851000	0.6043	0.6043
45012788- 8	3.9202	289.24	45.99	2.522	1.2519	846000	0.6047	0.6048
45020488- 1	3.9712	289.18	46.60	2.754	1.3200	891600	0.6061	0.6062
45020488- 2	3.9663	289.11	46.56	2.738	1.3169	889700	0.6067	0.6068
45020488- 3	3.8423	288.37	45.22	6.193	1.9377	1313400	0.6022	0.6024
45020488- 4	3.8549	288.25	45.39	6.209	1.9451	1318600	0.6026	0.6028
45020488- 5	3.6901	288.01	43.49	8.868	2.2714	1543700	0.6015	0.6017
45020488- 6	3.6919	287.29	43.63	8.795	2.2651	1542100	0.6013	0.6016
45020488- 7	3.8698	288.31	45.56	5.073	1.7612	1193600	0.6026	0.6027
45020488- 8	3.8555	288.43	45.37	5.139	1.7700	1199400	0.6029	0.6031

Table B.4 Measured and calculated quantities for the 0.73 beta ratio plate with the oversized Sprenkle 47 pipe diameters upstream of the orifice plate (Configuration 1).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46071886- 1	3.9641	289.21	46.51	2.375	1.5326	1035400	0.6023	0.6024
46071886- 3	3.9408	289.24	46.23	2.353	1.5250	1030400	0.6039	0.6039
46071886- 4	3.8011	289.01	44.63	4.449	2.0477	1386600	0.6001	0.6002
46071886- 5	3.7938	288.90	44.56	4.442	2.0495	1388300	0.6015	0.6017
46071886- 6	3.5840	287.56	42.31	6.482	2.4079	1640500	0.6005	0.6007
46071886- 7	3.5760	286.74	42.34	6.382	2.3917	1632800	0.6008	0.6010
46072986- 1	3.9262	289.06	46.10	2.437	1.5484	1046800	0.6034	0.6035
46072986- 2	3.9252	288.93	46.11	2.453	1.5571	1053000	0.6048	0.6048
46072986- 3	3.6464	288.22	42.94	6.425	2.4189	1644200	0.6014	0.6016
46072986- 4	3.6451	287.77	42.99	6.358	2.4047	1636300	0.6006	0.6008
46072986- 5	3.8038	288.31	44.78	4.418	2.0447	1386900	0.6003	0.6004
46072986- 6	3.8028	288.18	44.79	4.454	2.0577	1396100	0.6016	0.6017
46080186- 3	3.6677	287.95	43.23	6.636	2.4718	1680800	0.6026	0.6028
46080186- 4	3.6674	287.91	43.24	6.566	2.4581	1671600	0.6025	0.6026
46080186- 5	3.9528	288.52	46.50	2.451	1.5637	1058200	0.6049	0.6050
46080186- 6	3.9521	288.52	46.50	2.478	1.5705	1062800	0.6043	0.6043
46012788- 1	3.6959	287.92	43.57	5.364	2.2226	1510900	0.6004	0.6006
46012788- 2	3.6913	287.79	43.54	5.428	2.2391	1522600	0.6016	0.6017
46012788- 3	3.8199	288.44	44.95	3.866	1.9178	1300100	0.6008	0.6009
46012788- 4	3.8059	288.03	44.85	3.853	1.9119	1297600	0.6007	0.6008
46012788- 5	3.8809	288.56	45.65	2.766	1.6379	1109200	0.6020	0.6021
46012788- 6	3.8770	288.65	45.59	2.781	1.6434	1112800	0.6029	0.6029
46012788- 7	3.7509	287.99	44.21	4.677	2.0965	1423900	0.6022	0.6023
46012788- 8	3.7515	288.31	44.16	4.679	2.0921	1419900	0.6011	0.6012
46012888- 1	3.7667	288.54	44.30	4.660	2.0902	1417500	0.6008	0.6009
46012888- 2	3.7591	288.57	44.21	4.638	2.0807	1411100	0.6001	0.6002
46012888- 3	3.8742	288.69	45.55	2.758	1.6330	1105600	0.6019	0.6019
46012888- 4	3.8631	288.71	45.41	2.764	1.6337	1106200	0.6023	0.6023
46012888- 5	3.8129	288.61	44.84	3.710	1.8751	1270700	0.6005	0.6006
46012888- 6	3.8088	288.57	44.80	3.694	1.8688	1266600	0.6000	0.6001
46012888- 7	3.6772	287.66	43.39	5.572	2.2632	1539700	0.6011	0.6012
46012888- 8	3.6822	288.26	43.35	5.579	2.2618	1536500	0.6006	0.6008

Table B.5 Measured and calculated quantities for the 0.43 beta ratio plate with 58 pipe diameters of straight pipe upstream of the orifice plate (Configuration 2).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43012887- 1	3.9481	287.06	46.71	30.406	1.6023	1088200	0.6015	0.6025
43012887- 2	3.9424	287.21	46.62	30.310	1.5975	1084600	0.6012	0.6022
43012887- 3	4.1027	290.14	47.98	9.228	0.8988	604800	0.6050	0.6053
43012887- 4	4.0908	290.47	47.78	9.193	0.8955	602200	0.6052	0.6055
43012887- 5	3.8498	287.88	45.40	47.508	1.9746	1340000	0.6009	0.6025
43012887- 6	3.8598	288.83	45.35	47.331	1.9704	1334000	0.6011	0.6026
43070187- 1	3.8569	285.19	45.96	47.532	1.9891	1358600	0.6015	0.6031
43070187- 2	3.8302	288.27	45.10	50.537	2.0270	1374600	0.5999	0.6016
43070187- 3	3.9672	287.88	46.79	13.183	1.0542	714400	0.6011	0.6015
43070187- 4	3.9854	288.06	46.97	13.297	1.0616	718900	0.6015	0.6020
43070187- 5	3.9344	288.66	46.26	27.769	1.5237	1031000	0.6015	0.6024
43070187- 6	3.9360	288.19	46.36	27.613	1.5244	1032600	0.6028	0.6037
43070887- 1	4.0990	291.18	47.74	4.468	0.6196	415900	0.6011	0.6012
43070887- 2	4.1206	291.12	48.01	4.789	0.6446	432700	0.6024	0.6026
43070887- 3	4.1324	291.08	48.15	4.067	0.5960	400100	0.6036	0.6037
43070887- 4	3.8309	289.21	44.95	49.469	1.9988	1352400	0.5990	0.6006
43070887- 5	3.8345	289.57	44.93	49.653	2.0005	1352300	0.5985	0.6002
43070887- 6	4.0639	290.32	47.49	13.529	1.0790	726100	0.6028	0.6032
43070887- 7	4.0614	290.14	47.49	13.571	1.0797	726900	0.6022	0.6026
43070887- 8	3.9635	289.57	46.44	27.261	1.5123	1020700	0.6013	0.6022
43070887- 9	3.9660	289.18	46.54	26.886	1.5024	1015000	0.6010	0.6018

Table B.6 Measured and calculated quantities for the 0.55 beta ratio plate with 58 pipe diameters of straight pipe upstream of the orifice plate (Configuration 2).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44063087- 1	4.0774	286.34	48.38	3.045	0.8824	599400	0.6042	0.6043
44063087- 2	4.0768	286.07	48.43	3.322	0.9222	626900	0.6042	0.6043
44063087- 3	4.0036	288.81	47.05	8.041	1.4126	954700	0.6033	0.6035
44063087- 4	3.9964	288.63	47.00	7.986	1.4074	951700	0.6035	0.6037
44063087- 5	3.7175	289.56	43.55	23.359	2.3030	1559000	0.5993	0.6000
44063087- 6	3.7077	289.38	43.47	23.329	2.2965	1555400	0.5986	0.5993
44063087- 7	3.8492	287.52	45.46	14.959	1.8854	1280600	0.6004	0.6009
44063087- 8	3.8490	288.97	45.20	15.106	1.8855	1276200	0.5992	0.5996
44070287- 1	3.9635	288.59	46.62	7.912	1.3979	945700	0.6047	0.6049
44070287- 2	3.9599	287.89	46.70	7.895	1.3910	942700	0.6018	0.6021
44070287- 3	3.8871	288.38	45.75	14.588	1.8665	1264600	0.5999	0.6004
44070287- 4	3.8833	287.60	45.84	14.456	1.8620	1264000	0.6007	0.6011
44070287- 5	3.7015	286.91	43.81	24.402	2.3636	1610600	0.6000	0.6008
44070287- 6	3.7438	288.68	44.01	22.452	2.2692	1538900	0.5992	0.5999
44070287- 7	4.0979	289.49	48.04	3.518	0.9461	637700	0.6047	0.6048
44070287- 8	4.0687	288.69	47.84	3.335	0.9202	621600	0.6053	0.6054

Table B.7 Measured and calculated quantities for the 0.67 beta ratio plate with 58 pipe diameters of straight pipe upstream of the orifice plate (Configuration 2).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45070187- 2	3.9718	288.47	46.74	4.699	1.7174	1162100	0.6028	0.6029
45070187- 3	3.9667	288.13	46.74	4.681	1.7140	1160800	0.6028	0.6029
45070187- 4	4.0152	288.43	47.26	2.673	1.3074	884300	0.6051	0.6052
45070187- 5	4.0145	289.12	47.12	2.665	1.3053	881500	0.6059	0.6059
45070187- 6	3.9105	287.96	46.10	6.538	2.0155	1366500	0.6038	0.6039
45070187- 7	3.9024	288.42	45.93	6.565	2.0125	1363100	0.6028	0.6030
45070287- 1	3.9035	288.19	45.98	6.415	2.0005	1355700	0.6058	0.6060
45070287- 2	3.8909	288.20	45.83	6.392	1.9877	1347200	0.6040	0.6042
45070287- 3	4.0010	288.48	47.08	2.879	1.3595	919600	0.6074	0.6075
45070287- 4	4.0016	288.69	47.05	2.885	1.3605	919800	0.6074	0.6075
45070287- 5	3.9430	287.86	46.51	4.946	1.7681	1198600	0.6063	0.6065
45070287- 6	3.9418	288.34	46.41	4.957	1.7621	1193200	0.6043	0.6044
45070287- 7	3.9409	288.14	46.43	4.967	1.7633	1194600	0.6039	0.6041
45070287- 8	3.7421	287.97	44.11	9.276	2.3487	1595600	0.6038	0.6041
45070287- 9	3.7321	287.65	44.04	9.201	2.3260	1581600	0.6008	0.6011
45070287-10	3.7422	288.46	44.03	9.226	2.3315	1582000	0.6015	0.6018

Table B.8 Measured and calculated quantities for the 0.73 beta ratio plate with 58 pipe diameters of straight pipe upstream of the orifice plate (Configuration 2).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46012887- 1	3.9710	288.80	46.67	2.581	1.6093	1088100	0.6056	0.6057
46012887- 2	3.9657	290.08	46.38	2.590	1.6033	1080800	0.6041	0.6042
46012887- 3	3.7596	286.45	44.57	5.762	2.3362	1592600	0.6020	0.6022
46012887- 4	3.7517	287.11	44.37	5.732	2.3224	1580900	0.6014	0.6015
46012887- 5	3.8871	287.69	45.88	3.864	1.9491	1322700	0.6046	0.6047
46012887- 6	3.8685	288.97	45.43	3.805	1.9258	1303200	0.6049	0.6050
46012887- 7	3.8571	290.03	45.11	3.787	1.9140	1292100	0.6047	0.6048
46012887- 8	3.9494	290.76	46.07	2.616	1.6048	1080300	0.6037	0.6038

Table B.9 Measured and calculated quantities for the 0.43 beta ratio plate with 10 pipe diameters from the elbow to the in-line tube bundle and 7 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 3).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43013087- 1	3.8491	288.53	45.28	47.797	1.9660	1332100	0.5973	0.5988
43013087- 2	3.8485	287.61	45.43	47.353	1.9619	1332300	0.5978	0.5994
43013087- 3	4.1003	287.06	48.52	9.285	0.8996	609800	0.6004	0.6007
43013087- 4	4.0888	285.93	48.59	9.284	0.9086	617800	0.6061	0.6064
43013087- 5	4.0991	286.15	48.68	9.284	0.9042	614300	0.6026	0.6028
43013087- 6	4.1027	287.02	48.55	9.302	0.9064	614500	0.6042	0.6045
43013087- 7	3.9520	286.74	46.81	29.667	1.5803	1074100	0.6000	0.6009
43013087- 8	3.9515	287.20	46.73	29.534	1.5738	1068500	0.5994	0.6004
43013087- 9	3.9506	287.81	46.61	29.531	1.5728	1066300	0.5998	0.6008
43020387- 1	3.9117	287.09	46.27	30.619	1.5940	1083000	0.5991	0.6001
43020387- 2	3.9106	287.07	46.26	30.625	1.5935	1082700	0.5989	0.5999
43020387- 3	4.0552	286.23	48.14	8.930	0.8796	597800	0.6010	0.6013
43020387- 4	4.0635	286.28	48.23	8.991	0.8828	599800	0.6006	0.6009
43020387- 5	3.8409	284.47	45.89	48.221	1.9874	1360100	0.5971	0.5987
43020387- 6	3.8358	288.65	45.10	49.456	1.9954	1351800	0.5970	0.5987

Table B.10 Measured and calculated quantities for the 0.55 beta ratio plate with 10 pipe diameters from the elbow to the in-line tube bundle and 7 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 3).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44020387- 1	3.9062	286.34	46.34	11.637	1.6707	1137200	0.5976	0.5979
44020387- 2	3.9055	289.63	45.75	11.776	1.6725	1129500	0.5984	0.5988
44020387- 3	4.0908	288.25	48.18	2.865	0.8508	575200	0.6018	0.6019
44020387- 4	4.0963	288.28	48.24	2.857	0.8508	575100	0.6023	0.6024
44020387- 5	3.7230	287.90	43.90	23.927	2.3328	1585400	0.5974	0.5982
44020387- 6	3.7217	288.00	43.86	23.835	2.3216	1577400	0.5960	0.5967

Table B.11 Measured and calculated quantities for the 0.67 beta ratio plate with 10 pipe diameters from the elbow to the in-line tube bundle and 7 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 3).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45020287- 1	3.8723	288.35	45.58	4.953	1.7276	1170800	0.5980	0.5982
45020287- 2	3.8782	289.58	45.44	4.960	1.7228	1163900	0.5968	0.5970
45020287- 3	3.7413	290.17	43.73	8.452	2.2074	1491600	0.5971	0.5973
45020287- 4	3.7312	289.08	43.79	8.394	2.2006	1491100	0.5969	0.5971
45020287- 5	3.9503	284.18	47.26	2.525	1.2608	862300	0.6005	0.6005
45020287- 6	3.9528	284.66	47.20	2.534	1.2609	861300	0.5999	0.6000

Table B.12 **Measured and calculated quantities for the 0.73 beta ratio plate with 10 pipe diameters from the elbow to the in-line tube bundle and 7 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 3).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46013087- 1	3.9680	286.88	46.98	2.575	1.6000	1086900	0.6008	0.6009
46013087- 2	3.9624	286.81	46.92	2.573	1.5985	1086100	0.6008	0.6009
46013087- 3	3.7545	289.26	44.04	5.868	2.3059	1561400	0.5924	0.5925
46013087- 4	3.7509	288.91	44.05	5.838	2.3007	1559200	0.5924	0.5925
46013087- 5	3.7481	288.16	44.15	5.830	2.3021	1563100	0.5926	0.5927
46013087- 6	3.9083	288.11	46.05	3.777	1.9025	1289500	0.5958	0.5959
46013087- 7	3.9059	287.29	46.17	3.758	1.8983	1289200	0.5953	0.5954
46020387- 1	3.9482	289.33	46.31	2.542	1.5753	1064000	0.5997	0.5997
46020387- 2	3.9495	288.31	46.50	2.527	1.5684	1062000	0.5976	0.5977
46020387- 3	3.7327	287.03	44.16	6.073	2.3638	1609700	0.5961	0.5962
46020387- 4	3.7325	288.99	43.82	6.095	2.3516	1593800	0.5942	0.5943
46020387- 5	3.9146	289.17	45.94	3.679	1.8744	1267100	0.5954	0.5955
46020387- 6	3.9133	287.93	46.14	3.685	1.8774	1272900	0.5946	0.5947

Table B.13 **Measured and calculated quantities for the 0.55 beta ratio plate with 48 pipe diameters from the elbow to the in-line tube bundle and 7 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 4).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44070987- 1	3.9814	288.32	46.88	7.211	1.3284	899100	0.6003	0.6005
44070987- 2	3.9643	288.76	46.60	7.133	1.3171	890700	0.6002	0.6004
44070987- 3	3.7463	288.99	43.99	23.604	2.3102	1565500	0.5951	0.5958
44070987- 4	3.7215	290.75	43.41	23.490	2.2926	1547400	0.5959	0.5966
44070987- 5	3.8737	289.83	45.34	15.673	1.9172	1294600	0.5971	0.5976
44070987- 6	3.8917	290.47	45.44	15.814	1.9264	1298500	0.5966	0.5971
44070987- 7	4.1184	291.37	47.94	3.358	0.9196	616900	0.6023	0.6024
44070987- 8	4.0918	291.18	47.66	3.355	0.9179	616200	0.6032	0.6033
44071787- 1	3.9006	287.18	46.13	14.670	1.8696	1270100	0.5968	0.5973
44071787- 2	3.9042	287.06	46.19	14.668	1.8732	1272900	0.5977	0.5981
44071787- 3	3.9810	287.54	47.01	8.317	1.4276	968100	0.5998	0.6000
44071787- 4	3.9802	287.36	47.04	8.308	1.4231	965500	0.5981	0.5983
44071787- 5	3.7563	288.02	44.27	21.998	2.2406	1521700	0.5960	0.5967
44071787- 6	3.7482	287.26	44.30	21.963	2.2398	1524100	0.5960	0.5967
44071787- 7	4.0850	288.43	48.08	2.776	0.8367	565400	0.6018	0.6019
44071787- 8	4.0745	288.66	47.92	2.816	0.8415	568400	0.6019	0.6020

Table B.14 **Measured and calculated quantities for the 0.73 beta ratio plate with 48 pipe diameters from the elbow to the in-line tube bundle and 7 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 4).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46070887- 1	3.7654	287.79	44.42	5.807	2.3091	1568900	0.5938	0.5939
46070887- 2	3.7685	288.71	44.30	5.821	2.3057	1563100	0.5930	0.5931
46070887- 3	3.8276	288.16	45.09	5.007	2.1613	1466100	0.5940	0.5942
46070887- 4	3.8193	288.37	44.95	5.012	2.1593	1464200	0.5941	0.5942
46070887- 5	3.9753	287.82	46.90	2.694	1.6154	1094700	0.5936	0.5937
46070887- 6	3.9570	288.51	46.55	2.700	1.6105	1089900	0.5932	0.5933
46070887- 7	3.8929	288.21	45.85	3.805	1.9063	1292000	0.5961	0.5962
46070887- 8	3.9111	287.88	46.12	3.788	1.9034	1290800	0.5947	0.5948
46070987- 1	3.8377	289.61	44.96	4.572	2.0698	1399000	0.5961	0.5962
46070987- 2	3.8545	288.28	45.39	4.559	2.0731	1405500	0.5952	0.5953
46070987- 3	3.9035	288.09	46.00	3.661	1.8693	1267100	0.5949	0.5950
46070987- 4	3.8968	288.20	45.90	3.659	1.8644	1263500	0.5942	0.5942
46070987- 5	3.7232	287.48	43.97	6.120	2.3609	1606200	0.5944	0.5945
46070987- 6	3.7271	288.55	43.83	6.145	2.3585	1600200	0.5934	0.5936
46070987- 7	3.9553	286.40	46.91	2.736	1.6334	1111000	0.5956	0.5956
46070987- 8	3.9393	286.11	46.78	2.746	1.6348	1113000	0.5958	0.5959

Table B.15 Measured and calculated quantities for the 0.43 beta ratio plate with 10 pipe diameters from the elbow to the in-line Sprenkle and 7 pipe diameters from the in-line Sprenkle to the orifice plate (Configuration 5).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43020587- 1	3.9130	286.90	46.32	30.603	1.5940	1083500	0.5990	0.6000
43020587- 2	3.9122	286.73	46.34	30.500	1.5941	1084000	0.5999	0.6009
43020587- 3	3.9113	287.04	46.28	30.437	1.5890	1079700	0.5990	0.6000
43020587- 4	4.0922	286.01	48.62	7.921	0.8330	566200	0.6014	0.6016
43020587- 5	4.0918	285.55	48.70	7.882	0.8318	566000	0.6015	0.6018
43020587- 6	3.8374	287.45	45.33	48.720	1.9893	1351600	0.5982	0.5998
43020587- 7	3.8378	287.11	45.39	49.807	2.0114	1367700	0.5978	0.5994
43020687- 1	3.9333	289.74	46.06	28.917	1.5474	1044400	0.5998	0.6008
43020687- 2	3.9346	286.12	46.72	28.460	1.5439	1051100	0.5991	0.6000
43020687- 3	3.8276	287.15	45.26	49.824	2.0118	1368000	0.5987	0.6003
43020687- 4	3.8293	288.86	44.99	49.664	1.9996	1354100	0.5978	0.5994
43020687- 5	4.0871	285.61	48.63	8.459	0.8600	585100	0.6007	0.6009
43020687- 6	4.0849	289.18	47.94	8.688	0.8679	585500	0.6024	0.6027

Table B.16 Measured and calculated quantities for the 0.55 beta ratio plate with 10 pipe diameters from the elbow to the in-line Sprenkle and 7 pipe diameters from the in-line Sprenkle to the orifice plate (Configuration 5).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44020687- 1	3.9220	289.51	45.97	11.218	1.6350	1104200	0.5980	0.5983
44020687- 2	3.9211	288.78	46.08	11.187	1.6339	1105500	0.5977	0.5980
44020687- 3	4.0902	289.25	47.99	2.550	0.8024	541200	0.6028	0.6029
44020687- 4	4.1071	289.99	48.05	2.553	0.8026	540300	0.6021	0.6022
44020687- 5	3.7638	289.60	44.09	22.960	2.2843	1545300	0.5959	0.5966
44020687- 6	3.7632	289.26	44.14	22.753	2.2720	1538200	0.5950	0.5957

Table B.17 Measured and calculated quantities for the 0.67 beta ratio plate with 10 pipe diameters from the elbow to the in-line Sprenkle and 7 pipe diameters from the in-line Sprenkle to the orifice plate (Configuration 5).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45020487- 1	3.9221	288.37	46.17	4.792	1.7111	1158800	0.5983	0.5985
45020487- 2	3.9233	287.50	46.34	4.770	1.7065	1158100	0.5970	0.5972
45020487- 3	3.7692	290.10	44.07	8.594	2.2319	1508000	0.5964	0.5966
45020487- 4	3.7665	289.92	44.07	8.538	2.2205	1501000	0.5953	0.5955
45020487- 5	3.9904	283.56	47.86	2.483	1.2556	859600	0.5993	0.5993
45020487- 6	3.9900	284.06	47.76	2.501	1.2574	859800	0.5986	0.5986

Table B.18 Measured and calculated quantities for the 0.73 beta ratio plate with 10 pipe diameters from the elbow to the in-line Sprenkle and 7 pipe diameters from the in-line Sprenkle to the orifice plate (Configuration 5).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46020487- 1	3.9544	288.92	46.45	2.463	1.5386	1040200	0.5942	0.5942
46020487- 2	3.9572	288.74	46.52	2.453	1.5364	1039100	0.5940	0.5940
46020487- 3	3.7237	289.32	43.67	5.995	2.3122	1566000	0.5901	0.5903
46020487- 4	3.7577	288.75	44.16	5.495	2.2254	1508700	0.5900	0.5901
46020487- 5	3.8914	290.23	45.48	3.942	1.9248	1298200	0.5936	0.5938
46020487- 6	3.8830	285.82	46.16	3.877	1.9167	1306700	0.5918	0.5919
46020687- 1	3.9599	289.38	46.44	2.497	1.5493	1046200	0.5942	0.5943
46020687- 2	3.9600	288.42	46.61	2.477	1.5453	1046000	0.5941	0.5941
46020687- 3	3.7381	292.97	43.24	5.967	2.2935	1539500	0.5896	0.5897
46020687- 4	3.7369	286.08	44.37	5.783	2.2908	1563500	0.5907	0.5908
46020687- 5	3.8921	289.21	45.67	3.842	1.8976	1283000	0.5916	0.5917
46020687- 6	3.8908	287.42	45.96	3.831	1.9006	1290600	0.5915	0.5916

Table B.19 **Measured and calculated quantities for the 0.55 beta ratio plate with 48 pipe diameters from the elbow to the in-line Sprenkle and 7 pipe diameters from the in-line Sprenkle to the orifice plate (Configuration 6).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44071787- 1	3.9933	287.33	47.20	7.676	1.3749	932700	0.6001	0.6004
44071787- 2	3.9815	287.35	47.05	7.598	1.3676	927800	0.6009	0.6011
44071787- 3	3.8911	286.84	46.07	14.709	1.8764	1275900	0.5986	0.5990
44071787- 4	3.8911	289.07	45.68	14.756	1.8696	1264500	0.5980	0.5984
44071787- 5	3.8994	289.27	45.74	14.780	1.8701	1264100	0.5972	0.5977
44071787- 6	4.1108	290.79	47.95	2.956	0.8612	578600	0.6010	0.6011
44071787- 7	4.0923	288.95	48.07	2.946	0.8609	581000	0.6011	0.6012
44071787- 8	3.7443	288.45	44.06	22.741	2.2831	1549100	0.5987	0.5994
44071787- 9	3.7505	289.37	43.97	22.719	2.2783	1542400	0.5983	0.5990
44072087- 1	3.7138	287.82	43.80	23.522	2.3008	1564100	0.5950	0.5957
44072087- 2	3.7028	286.59	43.88	23.309	2.2920	1563000	0.5949	0.5956
44072187- 1	4.0170	287.39	47.47	7.486	1.3542	918200	0.5968	0.5970
44072187- 2	3.9965	288.01	47.11	7.470	1.3516	915400	0.5986	0.5988
44072187- 3	3.9075	287.42	46.16	14.237	1.8426	1250900	0.5969	0.5973
44072187- 4	3.9067	287.17	46.20	14.163	1.8354	1246800	0.5959	0.5963
44072187- 5	4.0892	288.68	48.09	3.505	0.9392	634300	0.6011	0.6012
44072187- 6	4.0893	289.18	47.99	3.508	0.9369	632000	0.6000	0.6001

Table B.20 **Measured and calculated quantities for the 0.73 beta ratio plate with 48 pipe diameters from the elbow to the in-line Sprenkle and 7 pipe diameters from the in-line Sprenkle to the orifice plate (Configuration 6).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46072087- 2	3.8752	286.74	45.90	3.720	1.8699	1272100	0.5910	0.5911
46072087- 3	3.8762	287.19	45.83	3.705	1.8646	1267100	0.5910	0.5911
46072087- 5	3.9481	287.07	46.71	2.666	1.5951	1083300	0.5904	0.5905
46072087- 6	3.9180	287.22	46.32	2.640	1.5852	1076600	0.5921	0.5922
46072087- 7	3.7292	287.51	44.03	5.935	2.2999	1564500	0.5875	0.5877
46072087- 8	3.7208	287.27	43.97	5.893	2.2930	1560800	0.5883	0.5884
46072087- 9	3.8005	287.54	44.87	4.739	2.0874	1418600	0.5912	0.5913
46072087-10	3.7999	287.29	44.91	4.768	2.0908	1421800	0.5901	0.5902

Table B.21 **Measured and calculated quantities for the 0.43 beta ratio plate with 46 pipe diameters from the elbow to the flanged tube bundle and 9 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 7).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43100887- 1	3.9215	285.16	46.74	27.358	1.5188	1036600	0.6011	0.6019
43100887- 2	3.9042	283.20	46.89	26.975	1.5103	1035900	0.6010	0.6019
43100887- 3	3.8023	287.44	44.91	46.606	1.9411	1319300	0.5996	0.6012
43100887- 4	3.7837	286.16	44.91	48.844	1.9865	1354700	0.5994	0.6010
43100887- 5	4.1447	287.73	48.92	3.982	0.5947	402300	0.6038	0.6040
43100887- 6	4.1380	287.55	48.87	4.242	0.6143	415700	0.6045	0.6046
43100887- 7	4.0687	290.02	47.60	13.294	1.0722	722000	0.6036	0.6040
43100887- 8	4.0564	288.86	47.66	13.158	1.0697	722400	0.6049	0.6053
43100987- 1	4.0854	287.48	48.26	4.010	0.5918	400900	0.6030	0.6031
43100987- 2	4.0789	287.22	48.23	3.896	0.5842	396000	0.6040	0.6041
43100987- 3	3.8868	287.23	45.95	27.709	1.5143	1028700	0.6005	0.6014
43100987- 4	3.8879	287.14	45.98	27.581	1.5085	1025000	0.5994	0.6003
43100987- 5	3.9979	287.64	47.20	14.197	1.0989	744800	0.6011	0.6016
43100987- 6	3.9877	287.42	47.12	14.217	1.1001	746100	0.6019	0.6023
43100987- 7	3.7769	276.90	46.50	45.013	1.9397	1353600	0.5995	0.6011
43100987- 8	3.7665	287.61	44.46	48.603	1.9699	1338900	0.5989	0.6005

Table B.22 **Measured and calculated quantities for the 0.55 beta ratio plate with 46 pipe diameters from the elbow to the flanged tube bundle and 9 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 7).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44100687- 1	3.8427	287.19	45.43	15.027	1.8843	1280900	0.5989	0.5993
44100687- 2	3.8253	287.69	45.14	14.932	1.8756	1273700	0.5999	0.6004
44100687- 3	3.9108	287.73	46.15	8.390	1.4242	966100	0.6013	0.6016
44100687- 4	3.9065	286.61	46.30	8.354	1.4241	968700	0.6016	0.6018
44100687- 5	3.6612	282.08	44.15	22.145	2.2524	1553800	0.5981	0.5988
44100687- 6	3.6710	283.67	43.99	22.261	2.2547	1549100	0.5982	0.5989
44100687- 7	4.0271	289.38	47.23	3.313	0.9071	612000	0.6026	0.6027
44100687- 8	4.0102	286.63	47.53	3.329	0.9148	621500	0.6044	0.6045
44100787- 1	3.6632	283.81	43.87	22.517	2.2632	1554600	0.5978	0.5985
44100787- 2	3.6483	285.26	43.45	21.703	2.2101	1513000	0.5975	0.5982
44100787- 3	3.9059	288.17	46.01	8.408	1.4296	968800	0.6038	0.6041
44100787- 4	3.9077	288.04	46.06	8.640	1.4429	978000	0.6009	0.6011
44100787- 5	3.8088	287.61	44.96	15.085	1.8783	1276000	0.5989	0.5994
44100787- 6	3.8040	286.36	45.12	14.928	1.8722	1275900	0.5991	0.5996
44100787- 7	4.0183	287.86	47.40	2.746	0.8248	558600	0.6008	0.6009
44100787- 8	4.0317	287.64	47.60	2.784	0.8357	566100	0.6033	0.6033
44100787- 9	4.0645	287.29	48.05	2.790	0.8424	571000	0.6047	0.6048
44100787-10	3.9293	285.64	46.74	8.026	1.4055	958000	0.6029	0.6031

Table B.23 **Measured and calculated quantities for the 0.67 beta ratio plate with 46 pipe diameters from the elbow to the flanged tube bundle and 9 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 7).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45100887- 1	3.9431	285.53	46.93	4.586	1.7010	1159500	0.6032	0.6033
45100887- 2	3.9429	284.82	47.05	4.553	1.6985	1159800	0.6037	0.6038
45100887- 3	3.8440	282.29	46.32	6.268	1.9681	1353900	0.6009	0.6010
45100887- 4	3.8522	280.93	46.67	6.219	1.9724	1361300	0.6023	0.6024
45100887- 5	3.6943	278.87	45.11	8.919	2.3146	1608900	0.6002	0.6005
45100887- 6	3.6829	280.25	44.73	8.901	2.3018	1594700	0.6001	0.6003
45100887- 7	3.9346	289.29	46.15	3.238	1.4172	957500	0.6031	0.6032
45100887- 8	3.9360	289.38	46.15	3.311	1.4373	970800	0.6048	0.6049
45100987- 1	3.8097	286.81	45.11	6.260	1.9531	1329400	0.6045	0.6047
45100987- 2	3.8049	288.77	44.72	6.292	1.9478	1319600	0.6039	0.6041
45100987- 3	3.6844	282.58	44.34	8.633	2.2695	1563300	0.6034	0.6036
45100987- 4	3.6813	284.51	43.97	8.625	2.2585	1548300	0.6032	0.6034
45100987- 5	3.9326	288.68	46.24	2.671	1.2900	872800	0.6039	0.6040
45100987- 6	3.9405	288.78	46.31	2.718	1.3073	884200	0.6061	0.6062
45100987- 7	3.8578	287.48	45.56	5.116	1.7735	1204500	0.6042	0.6043
45100987- 8	3.8584	287.77	45.52	5.128	1.7737	1203800	0.6039	0.6040

Table B.24 **Measured and calculated quantities for the 0.73 beta ratio plate with 46 pipe diameters from the elbow to the flanged tube bundle and 9 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 7).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46100587- 1	3.8023	286.03	45.16	4.488	2.0672	1409800	0.5997	0.5998
46100587- 2	3.7634	284.94	44.88	4.711	2.1072	1441600	0.5986	0.5987
46100587- 3	3.8757	290.79	45.20	2.888	1.6669	1122900	0.6025	0.6026
46100587- 4	3.8728	287.03	45.82	2.866	1.6683	1134100	0.6014	0.6014
46100587- 5	3.8021	287.52	44.90	3.965	1.9428	1320200	0.6014	0.6015
46100587- 6	3.8100	287.62	44.97	3.943	1.9401	1318000	0.6017	0.6018
46100587- 7	3.6539	284.97	43.56	5.957	2.3372	1601000	0.5993	0.5994
46100587- 8	3.6531	285.75	43.42	5.940	2.3304	1593300	0.5993	0.5994
46100687- 1	3.6804	284.78	43.91	5.610	2.2780	1560700	0.5994	0.5996
46100687- 2	3.6794	286.86	43.55	5.609	2.2689	1546600	0.5995	0.5997
46100687- 3	3.7645	288.97	44.21	4.817	2.1187	1435400	0.5996	0.5997
46100687- 4	3.7591	285.49	44.73	4.774	2.1190	1447900	0.5989	0.5990
46100687- 5	3.8195	283.91	45.74	3.898	1.9405	1330000	0.6003	0.6004
46100687- 6	3.8158	288.42	44.90	3.997	1.9457	1319100	0.5999	0.6000
46100687- 7	3.8151	285.82	45.35	3.966	1.9456	1327400	0.5993	0.5993
46100687- 8	3.8967	288.61	45.83	2.667	1.6101	1090000	0.6015	0.6015
46100687- 9	3.8844	289.18	45.58	2.684	1.6117	1089800	0.6019	0.6019

Table B.25 Measured and calculated quantities for the 0.43 beta ratio plate with 44 pipe diameters from the elbow to the flanged tube bundle and 12 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 8).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43101487- 1	3.7688	287.17	44.56	46.992	1.9420	1321300	0.5998	0.6014
43101487- 2	3.7454	286.93	44.32	47.971	1.9539	1330500	0.5988	0.6005
43101487- 3	3.9188	287.73	46.24	14.740	1.1093	752400	0.6016	0.6021
43101487- 4	3.9236	287.74	46.30	14.953	1.1161	756900	0.6006	0.6011
43101487- 5	3.8792	286.15	46.05	28.150	1.5274	1040500	0.6003	0.6012
43101487- 6	3.8698	286.00	45.97	27.889	1.5189	1035100	0.6002	0.6011
43101487- 7	4.1154	288.07	48.51	3.841	0.5820	393500	0.6043	0.6044
43101487- 8	4.1018	288.43	48.28	3.841	0.5817	393000	0.6053	0.6054
43101587- 1	3.9674	287.41	46.88	12.245	1.0194	691600	0.6026	0.6030
43101587- 2	3.9615	286.54	46.96	11.905	1.0045	682900	0.6017	0.6021
43101587- 3	3.7892	286.19	44.97	46.789	1.9404	1323100	0.5979	0.5995
43101587- 4	3.7896	285.58	45.08	46.454	1.9382	1323500	0.5986	0.6002
43101587- 5	4.1505	288.18	48.90	3.937	0.5905	399000	0.6031	0.6032
43101587- 6	4.1597	287.88	49.07	4.464	0.6320	427300	0.6051	0.6053
43101587- 7	3.9413	288.56	46.36	26.527	1.4940	1011000	0.6028	0.6037
43101587- 8	3.9386	287.99	46.43	26.219	1.4822	1004500	0.6011	0.602

Table B.26 Measured and calculated quantities for the 0.55 beta ratio plate with 44 pipe diameters from the elbow to the flanged tube bundle and 12 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 8).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44093087- 1	3.8460	287.33	45.45	15.088	1.8933	1286500	0.6004	0.6009
44093087- 2	3.8390	285.17	45.75	14.806	1.8814	1285200	0.6004	0.6008
44093087- 3	4.0622	286.37	48.19	3.208	0.9046	614500	0.6046	0.6047
44093087- 4	4.0621	286.37	48.19	3.180	0.9012	612200	0.6049	0.6050
44093087- 5	3.9559	285.83	47.03	7.257	1.3428	914500	0.6039	0.6041
44093087- 6	3.9533	288.43	46.53	7.269	1.3363	904500	0.6037	0.6039
44093087- 7	3.7027	284.37	44.25	22.610	2.2864	1567600	0.6000	0.6008
44093087- 8	3.7229	284.21	44.52	22.300	2.2769	1561300	0.5999	0.6006
44100187- 1	3.8387	286.42	45.52	14.431	1.8569	1264700	0.6017	0.6021
44100187- 2	3.8336	286.34	45.48	14.386	1.8543	1263200	0.6021	0.6025
44100187- 3	3.9364	288.34	46.34	7.721	1.3812	935300	0.6066	0.6068
44100187- 4	3.9703	288.17	46.77	7.726	1.3841	937200	0.6049	0.6051
44100187- 5	3.9413	288.18	46.43	7.673	1.3751	931400	0.6052	0.6055
44100187- 6	4.0529	289.97	47.42	2.832	0.8441	568500	0.6052	0.6053
44100187- 7	4.0540	288.87	47.64	2.809	0.8454	570900	0.6073	0.6074
44100187- 8	3.6985	285.17	44.07	22.054	2.2602	1546600	0.6019	0.6026
44100187- 9	3.6877	287.41	43.56	22.712	2.2771	1549900	0.6009	0.6017

Table B.27 Measured and calculated quantities for the 0.67 beta ratio plate with 44 pipe diameters from the elbow to the flanged tube bundle and 12 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 8).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45101487- 1	3.8140	287.76	45.00	6.101	1.9179	1302400	0.6020	0.6022
45101487- 2	3.8062	288.02	44.86	6.064	1.9090	1295600	0.6020	0.6022
45101487- 3	3.8614	284.89	46.07	4.602	1.6902	1155100	0.6039	0.6040
45101487- 4	3.8542	288.07	45.42	4.683	1.6929	1148200	0.6038	0.6039
45101487- 5	3.9259	287.58	46.35	2.844	1.3371	907100	0.6058	0.6059
45101487- 6	3.9031	287.38	46.12	2.832	1.3311	903800	0.6059	0.6060
45101487- 7	3.6568	278.34	44.75	8.462	2.2486	1565900	0.6012	0.6014
45101487- 8	3.6714	280.37	44.57	8.497	2.2500	1558600	0.6014	0.6017
45101687- 1	3.7255	286.97	44.08	8.342	2.2146	1508300	0.6007	0.6009
45101687- 2	3.7249	286.60	44.14	8.256	2.2049	1503100	0.6007	0.6010
45101687- 3	3.7818	289.10	44.39	7.233	2.0683	1400500	0.6003	0.6005
45101687- 4	3.7740	288.36	44.42	7.199	2.0722	1405800	0.6027	0.6029
45101687- 5	3.7789	288.86	44.39	7.231	2.0736	1404900	0.6019	0.6021
45101687- 6	3.9501	288.69	46.44	2.701	1.3037	881900	0.6055	0.6056
45101687- 7	3.9279	288.59	46.20	2.714	1.3044	882800	0.6060	0.6061
45101687- 8	3.8577	285.16	45.97	4.973	1.7547	1198500	0.6037	0.6038
45101687- 9	3.8518	288.64	45.29	4.896	1.7291	1171200	0.6040	0.6041

Table B.28 Measured and calculated quantities for the 0.73 beta ratio plate with 44 pipe diameters from the elbow to the flanged tube bundle and 12 pipe diameters from the flanged tube bundle to the orifice plate (Configuration 8).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46092987- 1	3.8544	288.60	45.33	3.875	1.9323	1308900	0.6022	0.6023
46092987- 2	3.8549	288.11	45.42	3.840	1.9237	1304600	0.6016	0.6017
46092987- 3	3.9225	289.29	46.01	2.620	1.6042	1083900	0.6035	0.6035
46092987- 4	3.9219	284.84	46.80	2.584	1.6089	1098900	0.6044	0.6045
46092987- 5	3.7617	287.05	44.50	5.058	2.1850	1487200	0.6015	0.6016
46092987- 6	3.7637	289.24	44.15	5.109	2.1882	1481500	0.6017	0.6018
46092987- 7	3.7031	279.17	45.17	5.514	2.2972	1595500	0.6013	0.6015
46092987- 8	3.6917	273.04	46.16	5.539	2.3276	1642100	0.6015	0.6016
46093087- 1	3.6774	284.90	43.86	5.906	2.3402	1602800	0.6006	0.6007
46093087- 2	3.6807	282.48	44.31	5.752	2.3241	1601300	0.6013	0.6015
46093087- 3	3.9084	287.27	46.20	2.709	1.6330	1108900	0.6029	0.6030
46093087- 4	3.8978	287.85	45.97	2.796	1.6543	1122000	0.6027	0.6028
46093087- 5	3.8509	287.45	45.49	3.684	1.8954	1287500	0.6048	0.6049
46093087- 6	3.8420	287.41	45.39	3.671	1.8865	1281700	0.6036	0.6037
46093087- 7	3.7598	287.70	44.36	4.899	2.1561	1465300	0.6040	0.6041
46093087- 8	3.7646	286.76	44.58	4.868	2.1524	1466000	0.6035	0.6036
46100187- 1	3.9389	287.89	46.45	2.591	1.6033	1086800	0.6036	0.6037
46100187- 2	3.9374	287.72	46.46	2.577	1.5990	1084300	0.6036	0.6037
46100187- 3	3.8611	288.50	45.43	3.730	1.8963	1284700	0.6017	0.6018
46100187- 4	3.8578	288.13	45.45	3.690	1.8887	1280700	0.6023	0.6024
46100187- 5	3.6815	277.26	45.25	5.689	2.3203	1619700	0.5975	0.5976
46100187- 6	3.7703	284.26	45.08	4.866	2.1589	1479400	0.6021	0.6022
46100187- 7	3.7614	284.19	44.99	4.860	2.1533	1476000	0.6015	0.6017

Table B.29 Measured and calculated quantities for the 0.55 beta ratio plate with 44 pipe diameters from the elbow to the flanged Sprenkle and 12 pipe diameters from the flanged Sprenkle to the orifice plate (Configuration 9).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44101987- 1	3.6858	282.42	44.38	22.000	2.2360	1540700	0.5941	0.5948
44101987- 2	3.6813	277.32	45.23	21.549	2.2304	1556800	0.5932	0.5939
44101987- 3	4.0543	287.17	47.95	3.225	0.8977	608700	0.5999	0.6000
44101987- 4	4.0447	287.03	47.86	3.239	0.8996	610200	0.6004	0.6005
44101987- 5	3.9334	287.74	46.42	7.598	1.3539	918100	0.5989	0.5991
44101987- 6	3.9228	287.46	46.34	7.531	1.3422	910900	0.5969	0.5971
44101987- 7	3.8177	286.84	45.20	15.275	1.8871	1284200	0.5964	0.5969
44101987- 8	3.8374	285.58	45.66	15.106	1.8846	1286200	0.5960	0.5964
44102087- 1	3.6639	282.75	44.06	22.228	2.2528	1551500	0.5976	0.5983
44102087- 2	3.6662	282.84	44.07	22.168	2.2436	1544800	0.5959	0.5966
44102087- 3	3.9075	288.16	46.03	8.210	1.3985	947700	0.5976	0.5978
44102087- 4	3.9168	287.96	46.18	8.364	1.4187	961700	0.5997	0.5999
44102087- 5	3.8174	287.86	45.02	14.951	1.8662	1266900	0.5973	0.5978
44102087- 6	3.8133	288.53	44.86	14.916	1.8577	1259200	0.5964	0.5968
44102087- 7	4.0601	288.97	47.69	2.681	0.8170	551500	0.6004	0.6005

Table B.30 Measured and calculated quantities for the 0.73 beta ratio plate and 44 pipe diameters from the elbow to the flanged Sprenkle and 12 pipe diameters from the flanged Sprenkle to the orifice plate (Configuration 9).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46102087- 1	3.9159	286.96	46.35	2.539	1.5649	1063400	0.5959	0.5960
46102087- 2	3.9240	286.59	46.51	2.509	1.5572	1059000	0.5954	0.5955
46102087- 3	3.6839	286.61	43.65	5.730	2.2641	1544200	0.5913	0.5914
46102087- 4	3.6923	286.47	43.77	5.711	2.2611	1542500	0.5906	0.5908
46102087- 5	3.7718	291.61	43.85	4.768	2.0722	1394900	0.5918	0.5919
46102087- 6	3.7583	289.56	44.03	4.745	2.0711	1401300	0.5918	0.5919
46102087- 7	3.8313	287.67	45.22	3.537	1.8125	1230800	0.5920	0.5921
46102087- 8	3.8234	286.32	45.36	3.527	1.8121	1234700	0.5917	0.5918
46102087- 2	3.6797	285.88	43.72	5.672	2.2602	1544300	0.5928	0.5930
46102087- 3	3.6741	284.85	43.83	5.572	2.2394	1534100	0.5919	0.5920
46102087- 4	3.9026	289.12	45.81	2.570	1.5565	1052400	0.5924	0.5925
46102087- 5	3.8951	288.48	45.83	2.622	1.5780	1068700	0.5946	0.5946
46102087- 6	3.7963	286.79	44.95	4.366	2.0081	1367100	0.5920	0.5921
46102087- 7	3.7925	286.59	44.94	4.322	1.9988	1361500	0.5924	0.5925

Table B.31 Measured and calculated quantities for the 0.43 beta ratio plate with 34 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 12 pipe diameters from the in-line tube bundle to the orifice plate. In-line tube bundle installed in 2 diameter spool piece (Configuration 10).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43032288- 1	4.0738	289.81	47.70	12.726	1.0475	705700	0.6021	0.6025
43032288- 2	4.0807	289.79	47.78	12.788	1.0515	708300	0.6023	0.6027
43032288- 3	3.9737	289.32	46.61	26.635	1.4985	1011800	0.6018	0.6026
43032288- 4	3.9742	289.12	46.65	26.409	1.4932	1008700	0.6020	0.6028
43032488- 1	4.1412	290.12	48.43	4.209	0.6080	409000	0.6035	0.6036
43032488- 2	4.1414	290.08	48.44	4.410	0.6229	419000	0.6039	0.6040
43032488- 3	3.8513	287.91	45.41	46.023	1.9346	1312700	0.5981	0.5997
43032488- 4	3.8294	287.49	45.22	48.505	1.9828	1347000	0.5983	0.5999
43032488- 5	4.1613	289.03	48.87	4.725	0.6442	434300	0.6008	0.6009
43032488- 6	4.1617	289.31	48.82	4.632	0.6395	430900	0.6027	0.6029
43032488- 7	3.8638	287.46	45.64	47.930	1.9860	1348800	0.6001	0.6017
43032488- 8	3.8649	287.73	45.60	47.768	1.9723	1338600	0.5972	0.5988
43032488- 9	4.1168	288.53	48.44	13.795	1.1053	746400	0.6055	0.6059
43032488-10	4.1103	288.46	48.38	13.794	1.1029	745100	0.6046	0.6051
43032488-11	4.0017	288.02	47.17	28.298	1.5556	1053400	0.6025	0.6034
43032488-12	3.9702	288.02	46.80	28.062	1.5399	1043100	0.6013	0.6022
43032488-13	3.9695	288.11	46.77	28.055	1.5388	1042100	0.6010	0.6019
43032488-14	4.1859	289.28	49.11	4.333	0.6183	416500	0.6006	0.6008
43032488-15	4.1186	288.51	48.46	12.831	1.0604	716200	0.6022	0.6026

Table B.32 Measured and calculated quantities for the 0.73 beta ratio plate with 34 pipe diameters from an oversized Sprenkle to the in-line tube bundle and 12 pipe diameters from the in-line tube bundle to the orifice plate. In-line tube bundle installed in 2 diameter spool piece (Configuration 10).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46032288- 1	3.8097	288.74	44.78	4.707	2.0900	1415900	0.5945	0.5946
46032288- 2	3.8113	289.06	44.74	4.695	2.0916	1415800	0.5960	0.5961
46032288- 3	3.9361	289.37	46.16	2.632	1.5940	1076700	0.5973	0.5974
46032288- 4	3.9722	289.37	46.58	2.654	1.6089	1086300	0.5977	0.5978
46032288- 5	3.8935	289.08	45.71	3.629	1.8557	1255000	0.5951	0.5952
46032288- 6	3.9075	289.17	45.86	3.628	1.8632	1259500	0.5966	0.5966
46032288- 7	3.7419	288.69	43.99	5.631	2.2704	1539500	0.5958	0.5959
46032288- 8	3.7534	288.01	44.24	5.608	2.2693	1541200	0.5950	0.5952
46033088- 1	3.7865	289.13	44.44	4.775	2.0915	1416000	0.5930	0.5931
46033088- 2	3.7913	289.82	44.38	4.779	2.0960	1416600	0.5944	0.5945
46033088- 3	3.8555	289.52	45.18	3.834	1.8922	1278900	0.5938	0.5939
46033088- 4	3.8595	289.52	45.23	3.834	1.8963	1281600	0.5948	0.5949
46033088- 5	3.7140	289.40	43.54	5.711	2.2650	1533800	0.5932	0.5933
46033088- 6	3.7218	289.30	43.65	5.683	2.2639	1533200	0.5936	0.5938
46033088- 7	3.9361	289.73	46.09	2.574	1.5726	1061400	0.5964	0.5964
46033088- 8	3.9448	289.62	46.22	2.614	1.5866	1070900	0.5962	0.5963

Table B.33 Measured and calculated quantities for the 0.67 beta ratio plate with 33 pipe diameters from the elbow to the flanged tube bundle (hexagon pattern) and 12 pipe diameters from the in-line tube bundle (hexagon pattern) to the orifice plate (Configuration 11).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45102788- 1	3.9201	287.94	46.22	4.734	1.7125	1160900	0.6022	0.6023
45102788- 2	3.9297	287.93	46.34	4.727	1.7133	1161400	0.6022	0.6023
45102788- 3	3.7424	287.30	44.23	8.860	2.2890	1557400	0.6014	0.6016
45102788- 4	3.7375	287.30	44.17	8.827	2.2830	1553400	0.6013	0.6016
45102788- 5	3.8435	287.38	45.41	6.736	2.0215	1373500	0.6012	0.6014
45102788- 6	3.8660	287.35	45.68	6.822	2.0443	1388700	0.6023	0.6025
45102788- 7	3.9699	288.02	46.80	2.956	1.3658	925200	0.6041	0.6042
45102788- 8	3.9603	288.04	46.68	2.966	1.3634	923600	0.6028	0.6028

Table B.34 Measured and calculated quantities for the 0.73 beta ratio plate with 33 pipe diameters from the elbow to the flanged tube bundle (hexagon pattern) and 12 pipe diameters from the in-line tube bundle (hexagon pattern) to the orifice plate (Configuration 11).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46102788- 1	3.7664	287.56	44.47	5.244	2.2171	1507100	0.5996	0.5998
46102788- 2	3.7690	286.68	44.65	5.204	2.2138	1508000	0.5998	0.6000
46102788- 3	3.8758	287.68	45.74	3.795	1.9118	1297500	0.5993	0.5994
46102788- 4	3.8624	287.52	45.61	3.799	1.9122	1298500	0.6000	0.6001
46102788- 5	3.9288	287.95	46.32	2.785	1.6520	1119700	0.6007	0.6008
46102788- 6	3.9202	287.54	46.29	2.787	1.6522	1121100	0.6008	0.6008
46102788- 7	3.8198	287.61	45.09	4.516	2.0700	1406000	0.5991	0.5992
46102788- 8	3.8372	287.46	45.32	4.511	2.0783	1411900	0.6003	0.6004

Table B.35 Measured and calculated quantities for the 0.55 beta ratio plate with 33 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 12 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 11).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44090888- 1	3.9407	288.42	46.38	7.840	1.3802	934400	0.6013	0.6015
44090888- 2	3.9256	288.30	46.22	7.854	1.3800	934600	0.6017	0.6019
44090888- 3	3.8364	287.80	45.26	14.565	1.8493	1255300	0.5981	0.5986
44090888- 4	3.8395	287.59	45.33	14.485	1.8439	1252300	0.5976	0.5980
44090888- 5	3.7249	287.11	44.05	21.465	2.2159	1508700	0.5982	0.5989
44090888- 6	3.7268	287.07	44.08	21.390	2.2118	1506000	0.5979	0.5986
44090888- 7	4.0301	289.06	47.32	3.125	0.8822	595600	0.6028	0.6029
44090888- 8	4.0198	289.21	47.17	3.181	0.8911	601500	0.6044	0.6045
44091288- 1	3.8522	288.15	45.38	14.308	1.8387	1246800	0.5992	0.5997
44091288- 2	3.8393	288.12	45.23	14.257	1.8303	1241400	0.5985	0.5990
44091288- 3	4.0331	289.14	47.34	3.198	0.8924	602400	0.6027	0.6028
44091288- 4	4.0403	289.19	47.41	3.177	0.8942	603500	0.6054	0.6055
44091288- 5	3.9537	288.45	46.53	7.450	1.3512	914500	0.6029	0.6031
44091288- 6	3.9271	288.68	46.17	7.295	1.3285	898900	0.6013	0.6016
44091288- 7	3.7034	287.62	43.71	22.863	2.2820	1552200	0.5992	0.5999
44091288- 8	3.7241	287.55	43.97	22.894	2.2883	1556400	0.5987	0.5994

Table B.36 Measured and calculated quantities for the 0.67 beta ratio plate with 33 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 12 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 11).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45 92288- 1	3.9304	288.43	46.26	4.779	1.7313	1172200	0.6057	0.6058
45 92288- 2	3.9453	288.39	46.44	4.775	1.7296	1170900	0.6041	0.6042
45 92288- 3	3.7616	288.11	44.32	8.599	2.2593	1533800	0.6019	0.6021
45 92288- 4	3.7683	288.02	44.41	8.471	2.2438	1523600	0.6016	0.6018
45 92288- 5	3.9932	288.67	46.95	2.847	1.3440	908700	0.6047	0.6048
45 92288- 6	3.9899	288.79	46.89	2.878	1.3476	910900	0.6034	0.6035
45 92288- 7	3.8737	288.54	45.57	5.885	1.8960	1284100	0.6022	0.6023
45 92288- 8	3.8817	288.33	45.70	5.845	1.8892	1280100	0.6012	0.6014
45 92288- 9	3.9304	288.46	46.25	4.918	1.7455	1181700	0.6020	0.6021
45 92288-10	3.9195	288.44	46.13	4.918	1.7426	1179900	0.6018	0.6019
45 92388- 1	3.8653	288.69	45.44	5.787	1.8718	1267400	0.6004	0.6005
45 92388- 2	3.8560	288.48	45.37	5.793	1.8697	1266800	0.5998	0.6000
45 92388- 3	3.9516	288.98	46.41	2.789	1.3197	892000	0.6034	0.6034
45 92388- 4	3.9383	289.15	46.22	2.814	1.3209	892700	0.6025	0.6026
45 92388- 5	3.8942	288.46	45.82	4.680	1.6933	1146800	0.6014	0.6015
45 92388- 6	3.8925	288.57	45.78	4.667	1.6898	1144100	0.6013	0.6014
45 92388- 7	3.7179	287.69	43.87	8.956	2.2862	1554500	0.5998	0.6001
45 92388- 8	3.7125	287.32	43.87	8.903	2.2791	1551100	0.5997	0.6000

Table B.37 Measured and calculated quantities for the 0.73 beta ratio plate with 33 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 12 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 11).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46 92388- 1	3.8400	288.29	45.21	3.877	1.9177	1300100	0.5982	0.5983
46 92388- 2	3.8501	288.49	45.30	3.893	1.9223	1302500	0.5978	0.5979
46 92388- 3	3.9421	288.69	46.35	2.495	1.5631	1057400	0.6003	0.6004
46 92388- 4	3.9011	288.54	45.89	2.514	1.5592	1055700	0.5996	0.5996
46 92388- 5	3.7592	287.63	44.37	5.008	2.1564	1465700	0.5975	0.5976
46 92388- 6	3.7656	287.76	44.42	4.928	2.1406	1454400	0.5975	0.5976
46 92388- 7	3.7241	287.89	43.91	5.433	2.2395	1521900	0.5988	0.5989
46 92388- 8	3.7300	288.01	43.96	5.437	2.2380	1520300	0.5979	0.5980
46 92788- 1	3.6888	287.68	43.53	5.707	2.2761	1548200	0.5964	0.5966
46 92788- 2	3.7141	287.55	43.85	5.757	2.2933	1559900	0.5961	0.5962
46 92788- 3	3.7614	288.19	44.30	4.621	2.0741	1407800	0.5987	0.5988
46 92788- 4	3.7592	287.58	44.38	4.575	2.0654	1404000	0.5986	0.5987
46 92788- 5	3.8077	288.19	44.85	3.514	1.8178	1233200	0.5981	0.5981
46 92788- 6	3.8257	288.46	45.02	3.580	1.8384	1246100	0.5981	0.5982
46 92788- 7	3.8664	288.32	45.52	2.628	1.5905	1077900	0.6007	0.6008
46 92788- 8	3.8523	288.45	45.33	2.645	1.5946	1080500	0.6015	0.6016
46 92788- 9	3.8515	288.67	45.28	2.668	1.5959	1080800	0.5997	0.5997
46 92788-10	3.7392	288.23	44.03	4.631	2.0710	1406000	0.5989	0.5991

Table B.38 **Measured and calculated quantities for the 0.43 beta ratio plate with 38 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 17 pipe diameters from the in-line tube bundle to the orifice plate (configuration 12).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43122988- 1	3.9406	288.99	46.28	27.649	1.5167	1025300	0.5999	0.6008
43122988- 2	3.9265	288.98	46.11	27.485	1.5106	1021400	0.6003	0.6012
43122988- 3	4.1338	290.19	48.33	4.597	0.6352	427200	0.6037	0.6039
43122988- 4	4.1421	290.34	48.40	3.953	0.5887	395800	0.6031	0.6032
43122988- 5	3.8202	288.71	44.91	49.195	1.9942	1351000	0.5995	0.6012
43122988- 6	3.8246	288.65	44.97	48.884	1.9916	1349300	0.6003	0.6019
43122988- 7	4.0087	289.40	47.00	13.428	1.0679	720700	0.6019	0.6023
43122988- 8	3.9888	289.51	46.75	13.466	1.0675	720300	0.6024	0.6028

Table B.39 **Measured and calculated quantities for the 0.55 beta ratio plate with 38 pipe diameters from the elbow to the in-line tube bundle and 17 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 13).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44072387- 1	4.0771	288.41	47.99	3.183	0.9009	609000	0.6058	0.6059
44072387- 2	4.0598	289.17	47.65	3.185	0.8976	605700	0.6055	0.6056
44072387- 3	3.8951	287.11	46.07	14.377	1.8695	1270400	0.6032	0.6037
44072387- 4	3.8866	286.59	46.06	14.327	1.8675	1270700	0.6037	0.6042
44072387- 5	3.7401	288.52	43.99	22.914	2.3037	1562900	0.6022	0.6030
44072387- 6	3.7501	288.59	44.10	22.882	2.3015	1561000	0.6014	0.6021
44072387- 7	3.9708	290.11	46.44	8.173	1.4211	957900	0.6060	0.6062
44072387- 8	4.0102	290.30	46.86	8.130	1.4199	956200	0.6043	0.6045
44072487- 1	3.8964	286.80	46.14	7.913	1.3829	940400	0.6012	0.6015
44072487- 2	3.9041	286.56	46.28	7.892	1.3849	942200	0.6021	0.6023
44072487- 3	3.6924	288.93	43.36	23.131	2.2783	1545000	0.5971	0.5978
44072487- 4	3.6828	287.48	43.49	22.837	2.2707	1545500	0.5981	0.5988
44072487- 5	3.8028	289.22	44.61	15.687	1.9061	1290100	0.5983	0.5988
44072487- 6	3.8063	288.82	44.72	15.747	1.9141	1296700	0.5989	0.5994
44072487- 7	4.0211	287.36	47.52	3.190	0.8949	606800	0.6040	0.6041
44072487- 8	4.0331	289.38	47.30	3.237	0.9017	608400	0.6055	0.6056
44092287- 2	3.8593	288.22	45.45	7.474	1.3368	906300	0.6026	0.6028
44092287- 3	3.8573	287.36	45.58	7.418	1.3311	904300	0.6014	0.6016
44092287- 4	3.7603	280.93	45.55	14.400	1.8508	1278900	0.6003	0.6007
44092287- 5	3.7668	280.12	45.78	14.184	1.8387	1273000	0.5994	0.5998
44092287- 6	3.6386	278.47	44.50	21.373	2.2281	1551500	0.5999	0.6006
44092387- 1	3.6976	280.14	44.93	21.167	2.2208	1538800	0.5980	0.5986
44092387- 2	3.7079	278.03	45.43	20.875	2.2169	1544000	0.5978	0.5985
44092387- 3	4.0401	290.23	47.23	3.841	0.9740	655700	0.6008	0.6010
44092387- 4	4.0720	291.88	47.30	2.976	0.8614	577400	0.6032	0.6033

Table B.40 **Measured and calculated quantities for the 0.67 beta ratio plate with 38 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 17 pipe diameters from the in-line tube bundle to the orifice plate (configuration 12).**

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46122988- 1	3.9216	288.72	46.10	4.839	1.7351	1174000	0.6042	0.6044
46122988- 2	3.9165	288.92	46.01	4.819	1.7261	1167400	0.6030	0.6031
46122988- 3	3.9924	289.35	46.82	2.639	1.2941	873600	0.6056	0.6056
46122988- 4	4.0123	289.30	47.07	2.652	1.2980	876100	0.6043	0.6044
46122988- 5	3.7545	288.57	44.15	8.552	2.2539	1528600	0.6032	0.6034
46122988- 6	3.7431	287.79	44.15	8.484	2.2453	1525900	0.6033	0.6036
46122988- 7	3.8446	288.91	45.16	6.686	2.0134	1362900	0.6026	0.6028
46122988- 8	3.8371	288.22	45.19	6.691	2.0168	1367600	0.6032	0.6034

Table B.41 Measured and calculated quantities for the 0.73 beta ratio plate with 38 pipe diameters from the elbow to the in-line tube bundle and 17 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 13).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46072487- 1	3.9217	288.22	46.19	2.810	1.6651	1128100	0.6036	0.6037
46072487- 2	3.9119	286.24	46.42	2.789	1.6620	1131500	0.6033	0.6033
46072487- 3	3.8136	289.50	44.69	4.750	2.1182	1432500	0.6004	0.6005
46072487- 4	3.8210	289.63	44.76	4.723	2.1159	1430300	0.6010	0.6011
46072487- 5	3.8632	287.32	45.66	3.890	1.9490	1324200	0.6040	0.6041
46072487- 6	3.8586	287.62	45.55	3.902	1.9492	1323500	0.6038	0.6039
46072487- 7	3.7201	285.85	44.21	5.890	2.3520	1606500	0.6020	0.6022
46072487- 8	3.7365	284.91	44.56	5.875	2.3523	1610100	0.6004	0.6006
46092387- 1	3.9268	283.37	47.13	2.621	1.6200	1110400	0.6022	0.6023
46092387- 2	3.9347	285.41	46.85	2.634	1.6194	1104300	0.6022	0.6023
46092387- 3	3.8203	286.50	45.29	4.434	2.0577	1401500	0.5998	0.5999
46092387- 4	3.8125	285.72	45.33	4.531	2.0806	1419900	0.5997	0.5998
46092387- 5	3.8462	285.36	45.80	3.791	1.9158	1308000	0.6006	0.6007
46092387- 6	3.8396	284.89	45.80	3.767	1.9085	1304600	0.6002	0.6003
46092387- 7	3.6872	282.12	44.45	5.781	2.3293	1606200	0.6002	0.6003
46092387- 8	3.6800	278.18	45.06	5.651	2.3207	1616300	0.6008	0.6010

Table B.42 Measured and calculated quantities for the 0.43 beta ratio plate with the in-line tube bundle at the elbow and 17 diameters from the orifice plate (Configuration 14).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43081088- 1	4.0643	289.19	47.70	4.953	0.6542	441400	0.6030	0.6032
43081088- 2	4.0575	289.59	47.54	4.553	0.6265	422400	0.6033	0.6035
43081088- 3	3.8781	288.41	45.64	27.928	1.5149	1026300	0.6003	0.6013
43081088- 4	3.8728	288.39	45.58	27.520	1.5021	1017800	0.6000	0.6010
43081088- 5	3.7566	287.93	44.29	49.221	1.9764	1342400	0.5981	0.5998
43081088- 6	3.7658	287.82	44.41	48.795	1.9729	1340300	0.5989	0.6005
43081088- 7	3.9682	288.61	46.67	13.236	1.0574	715200	0.6024	0.6028
43081088- 8	3.9615	288.62	46.59	13.451	1.0632	719200	0.6014	0.6018
43081188- 1	3.9179	288.42	46.11	13.177	1.0484	709900	0.6022	0.6027
43081188- 2	3.9221	288.34	46.17	13.316	1.0556	714900	0.6028	0.6032
43081188- 3	3.8326	287.57	45.25	27.826	1.5068	1023400	0.6008	0.6017
43081188- 4	3.8302	287.56	45.22	27.684	1.4957	1016000	0.5981	0.5990
43081188- 5	4.0144	289.21	47.11	5.034	0.6571	443600	0.6046	0.6047
43081188- 6	4.0068	289.26	47.01	5.006	0.6548	442100	0.6048	0.6050
43081188- 7	3.7162	287.22	43.93	47.211	1.9348	1317100	0.6004	0.6020
43081188- 8	3.7172	287.24	43.94	46.765	1.9224	1308500	0.5993	0.6009

Table B.43 Measured and calculated quantities for the 0.55 beta ratio plate with the in-line tube bundle at the elbow and 17 diameters from the orifice plate (Configuration 14).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44080588- 1	3.9360	288.64	46.29	7.528	1.3561	917600	0.6036	0.6038
44080588- 2	3.9197	288.62	46.10	7.509	1.3489	912900	0.6023	0.6025
44080588- 3	3.8229	287.73	45.11	14.587	1.8550	1259600	0.6005	0.6010
44080588- 4	3.8331	288.07	45.17	14.476	1.8470	1253000	0.5998	0.6003
44080588- 5	4.0801	289.26	47.87	3.105	0.8899	600200	0.6066	0.6067
44080588- 6	4.0762	289.31	47.82	3.117	0.8919	601500	0.6071	0.6072
44080588- 7	3.6799	287.47	43.46	21.505	2.2143	1507100	0.6013	0.6020
44080588- 8	3.6828	287.43	43.50	21.345	2.2041	1500300	0.6005	0.6012
44081088- 1	3.8108	287.23	45.05	14.763	1.8614	1265600	0.5994	0.5998
44081088- 2	3.8082	287.09	45.04	14.672	1.8546	1261500	0.5991	0.5996
44081088- 3	4.0090	288.55	47.16	3.151	0.8873	600000	0.6048	0.6049
44081088- 4	3.9990	288.77	47.00	3.176	0.8912	602400	0.6061	0.6062
44081088- 5	3.9437	287.97	46.50	7.387	1.3448	911300	0.6028	0.6031
44081088- 6	3.9205	287.84	46.24	7.320	1.3358	905800	0.6032	0.6034
44081088- 7	3.6887	286.90	43.66	21.804	2.2257	1516800	0.5988	0.5995
44081088- 8	3.6972	286.15	43.88	21.675	2.2252	1519100	0.5989	0.5996

Table B.44 Measured and calculated quantities for the 0.67 beta ratio plate with the in-line tube bundle at the elbow and 17 diameters from the orifice plate (Configuration 14).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45080488- 1	3.6952	286.31	43.83	8.649	2.2848	1559200	0.6034	0.6036
45080488- 2	3.7109	285.65	44.13	6.665	2.2627	1546300	0.6018	0.6020
45080488- 3	3.8975	287.22	46.08	4.724	1.7116	1162700	0.6035	0.6036
45080488- 4	3.8782	286.94	45.90	4.750	1.7090	1161900	0.6020	0.6021
45080488- 5	3.8162	286.81	45.19	6.557	1.9989	1360500	0.6040	0.6042
45080488- 6	3.8225	287.26	45.18	6.605	2.0079	1365000	0.6045	0.6047
45080488- 7	3.9735	287.71	46.89	2.591	1.2840	870300	0.6059	0.6060
45080488- 8	3.9955	287.69	47.16	2.588	1.2884	873100	0.6067	0.6068
45081188- 1	3.7987	286.26	45.07	5.025	1.7461	1190300	0.6035	0.6036
45081188- 2	3.7829	287.12	44.74	5.021	1.7361	1181200	0.6025	0.6027
45081188- 3	3.6026	286.48	42.70	9.010	2.2655	1547100	0.6007	0.6009
45081188- 4	3.6244	285.89	43.06	8.379	2.2011	1504900	0.6027	0.6029
45081188- 5	3.7179	289.22	43.61	6.478	1.9461	1318300	0.6021	0.6023
45081188- 6	3.7273	290.12	43.58	6.527	1.9525	1319700	0.6021	0.6023
45081188- 7	3.8391	289.79	44.94	2.957	1.3419	906500	0.6055	0.6056
45081188- 8	3.8476	289.26	45.14	2.987	1.3484	912000	0.6040	0.6041

Table B.45 Measured and calculated quantities for the 0.73 beta ratio plate with the in-line tube bundle at the elbow and 17 diameters from the orifice plate (Configuration 14).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46080388- 1	3.9105	285.83	46.48	2.572	1.5763	1074200	0.5955	0.5956
46080388- 2	3.8976	285.78	46.34	2.580	1.5774	1075200	0.5959	0.5959
46080388- 3	3.7856	285.46	45.06	4.545	2.0611	1407900	0.5949	0.5950
46080388- 4	3.7787	286.63	44.77	4.537	2.0552	1400000	0.5956	0.5957
46080388- 5	3.8227	287.02	45.23	3.838	1.8980	1291000	0.5950	0.5951
46080388- 6	3.8232	287.15	45.21	3.846	1.9019	1293300	0.5957	0.5958
46080388- 8	3.6959	287.65	43.62	5.713	2.2786	1549900	0.5962	0.5963
46080488- 1	3.8567	288.08	45.45	3.692	1.8890	1281100	0.6023	0.6024
46080488- 2	3.8671	287.89	45.60	3.715	1.8926	1283900	0.6006	0.6007
46080488- 3	3.8653	288.19	45.53	3.705	1.8917	1282400	0.6015	0.6016
46080488- 4	3.8015	287.58	44.88	4.761	2.1233	1442700	0.5999	0.6000
46080488- 5	3.8094	287.58	44.97	4.788	2.1319	1448400	0.6000	0.6001
46080488- 6	3.7308	287.52	44.05	5.569	2.2721	1545300	0.5991	0.5992
46080488- 7	3.7278	287.54	44.01	5.564	2.2688	1543000	0.5988	0.5989
46080488- 8	3.9166	288.09	46.15	2.701	1.6309	1105200	0.6034	0.6034
46080488- 9	3.9087	288.03	46.07	2.723	1.6341	1107700	0.6026	0.6027
46080588- 1	3.8357	287.94	45.22	3.625	1.8587	1261300	0.5996	0.5997
46080588- 2	3.8378	288.22	45.20	3.624	1.8575	1259600	0.5994	0.5995
46080588- 3	3.6591	287.01	43.29	5.903	2.3203	1581400	0.5995	0.5996
46080588- 4	3.6699	284.11	43.90	5.839	2.3213	1593200	0.5988	0.5990
46080588- 5	3.9005	288.13	45.96	2.636	1.6054	1088100	0.6025	0.6026
46080588- 6	3.8956	288.03	45.92	2.637	1.6016	1085800	0.6011	0.6012
46080588- 7	3.7808	287.50	44.65	4.596	2.0814	1414800	0.6001	0.6002
46080588- 8	3.7825	287.48	44.67	4.575	2.0782	1412700	0.6004	0.6005

Table B.46 Measured and calculated quantities for the 0.43 beta ratio plate with 18 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 27 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 14).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 4.4445 cm (1.7498 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43040688- 1	3.9405	289.41	46.20	27.856	1.5277	1031800	0.6025	0.6034
43040688- 2	3.9282	289.32	46.07	27.299	1.5059	1017400	0.6008	0.6017
43040688- 3	3.8006	288.64	44.69	49.119	1.9834	1344200	0.5982	0.5999
43040688- 4	3.7983	288.88	44.62	48.808	1.9807	1341600	0.5998	0.6014
43040688- 5	4.0420	289.70	47.34	13.866	1.0902	734800	0.6025	0.6029
43040688- 6	4.0998	290.71	47.84	4.775	0.6441	432800	0.6038	0.6039
43040688- 7	4.1179	290.70	48.05	4.849	0.6498	436600	0.6032	0.6033
43040688- 1	4.0663	289.83	47.61	13.783	1.0857	731400	0.6001	0.6006

Table B.47 Measured and calculated quantities for the 0.55 beta ratio plate with 28 pipe diameters from the elbow to the in-line tube bundle and 27 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 15).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 5.7137 cm (2.2495 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44072287- 1	4.0775	288.91	47.90	3.194	0.8998	607500	0.6045	0.6046
44072287- 2	4.0648	289.00	47.74	3.186	0.9002	607700	0.6066	0.6067
44072287- 3	3.8974	286.76	46.16	13.898	1.8376	1249700	0.6025	0.6029
44072287- 4	3.8931	286.57	46.14	13.759	1.8228	1240200	0.6008	0.6012
44072287- 5	3.7300	286.96	44.14	22.924	2.3008	1567100	0.6004	0.6011
44072287- 6	3.7339	288.33	43.95	22.870	2.2948	1557700	0.6008	0.6015
44072287- 7	3.9622	287.33	46.83	8.505	1.4476	982400	0.6026	0.6029
44072287- 8	3.9836	286.86	47.17	8.624	1.4637	994200	0.6029	0.6032
44072387- 1	3.7607	286.07	44.65	21.657	2.2461	1532600	0.5996	0.6003
44072387- 2	3.7486	285.39	44.63	21.462	2.2342	1527200	0.5993	0.6000
44072387- 3	3.9778	290.43	46.46	8.010	1.4014	943800	0.6034	0.6037
44072387- 4	3.9788	293.06	46.01	8.169	1.4065	941300	0.6026	0.6028
44072387- 5	4.0814	289.87	47.78	3.355	0.9199	619600	0.6039	0.6040
44072387- 6	4.0685	288.96	47.79	3.335	0.9200	621100	0.6056	0.6057
44072387- 7	3.8860	290.26	45.41	15.271	1.9084	1287100	0.6017	0.6022
44072387- 8	3.8893	294.75	44.69	15.439	1.9036	1270300	0.6016	0.6021

Table B.48 Measured and calculated quantities for the 0.67 beta ratio plate with 18 pipe diameters from the oversized Sprenkle to the in-line tube bundle and 27 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 14).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 6.9840 cm (2.7496 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45040688- 1	3.8083	289.22	44.68	6.775	2.0204	1367200	0.6040	0.6041
45040688- 2	3.8062	289.13	44.67	6.769	2.0247	1370500	0.6056	0.6058
45040688- 3	3.9555	289.71	46.33	2.786	1.3280	896100	0.6080	0.6081
45040688- 4	3.9441	289.69	46.20	2.834	1.3373	902500	0.6080	0.6080
45040688- 5	3.8812	289.08	45.56	4.763	1.7208	1163900	0.6076	0.6077
45040688- 6	3.9038	289.32	45.79	4.768	1.7222	1163900	0.6063	0.6064
45040688- 7	3.6921	288.50	43.43	8.899	2.2855	1551400	0.6046	0.6048
45040688- 8	3.6893	288.16	43.45	8.817	2.2734	1544500	0.6040	0.6043

Table B.49 Measured and calculated quantities for the 0.73 beta ratio plate with 28 pipe diameters from the elbow to the in-line tube bundle and 27 pipe diameters from the in-line tube bundle to the orifice plate (Configuration 15).

Pipe Diameter = 10.368 cm (4.082 in) Orifice Diameter = 7.6177 cm (2.9991 in)

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPe)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46072187- 1	3.8285	287.84	45.15	4.727	2.1502	1459700	0.6078	0.6079
46072187- 2	3.8211	288.06	45.03	4.749	2.1436	1454600	0.6054	0.6055
46072187- 3	3.9517	287.17	46.73	2.677	1.6409	1114100	0.6059	0.6060
46072187- 4	3.9652	287.61	46.81	2.682	1.6461	1116300	0.6068	0.6068
46072187- 5	3.9193	286.96	46.39	3.660	1.9125	1299700	0.6062	0.6063
46072187- 6	3.9193	286.99	46.38	3.645	1.9077	1296300	0.6060	0.6061
46072187- 7	3.7587	287.96	44.31	5.894	2.3634	1605200	0.6039	0.6041
46072187- 8	3.7549	287.54	44.33	5.857	2.3511	1598600	0.6025	0.6026
46072287- 1	3.8929	288.54	45.79	3.848	1.9473	1318700	0.6058	0.6059
46072287- 2	3.8994	288.16	45.94	3.824	1.9380	1313500	0.6039	0.6040
46072287- 3	3.8460	287.36	45.44	4.832	2.1615	1468700	0.6024	0.6025
46072287- 4	3.8418	286.99	45.46	4.795	2.1504	1462600	0.6016	0.6017
46072287- 5	3.7435	289.88	43.81	5.788	2.3202	1568900	0.6017	0.6018
46072287- 6	3.7499	290.39	43.80	5.755	2.3121	1561400	0.6014	0.6015
46072287- 7	3.9418	287.97	46.47	2.535	1.5884	1076500	0.6044	0.6045
46072287- 8	3.9598	288.00	46.68	2.556	1.6009	1084700	0.6053	0.6054
46112087- 1	3.9422	288.88	46.32	2.603	1.6063	1086200	0.6043	0.6044
46112087- 2	3.9424	288.82	46.33	2.596	1.6039	1084700	0.6041	0.6042
46112087- 3	3.9475	288.78	46.40	2.575	1.5998	1082000	0.6046	0.6046
46112087- 4	3.9393	288.81	46.29	2.564	1.5928	1077300	0.6038	0.6038

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Standards are a framework for ensuring comparable, accurate, and repeatable results. Two orifice flow measurement standards are presently used, one in the United States (ANSI/API 2530[1]) and another in Europe (ISO 5167[2]). These two standards have significantly different specifications for installations. One important specification is the location of the flow conditioner relative to the orifice plate. Several recent European research reports [3,4] have shown that location specifications for flow conditioners in the standards are inadequate. Several different designs of flow conditioners were tested by these laboratories, but these designs are not commonly used in the United States.

As a result of the European findings, the National Institute of Standards and Technology (NIST) began a similar research program to determine the effect of the location of the flow conditioner using flow conditioners commonly used by the U.S natural gas industry. This research was sponsored by the Gas Research Institute (GRI). In this program, a 4-inch stainless steel orifice meter with an upstream surface finish of 0.7 μm (30 μin) was tested in nitrogen gas. Four orifice plates with beta ratios ranging from 0.43 to 0.73 were tested at pipe Reynolds numbers on the order of 10^6. Several types of tube bundle and Sprenkle flow conditioners were tested at five distances upstream of the orifice plate.

This research has shown that when an in-line flow conditioner is located 7 diameters from the orifice plate (the minimum distance specified in ANSI/API 2530[1] for a 0.75 beta ratio plate) the measured discharge coefficient can be as much as 1 percent less than that calculated by ANSI/API 2530[1]. There was no shift in the discharge coefficient for any beta ratio when the in-line tube bundle was located 17 pipe diameters from the orifice plate. The distance between a single elbow and the tube bundle flow conditioner was also found to be insignificant when the conditioner was 17 diameters upstream of the orifice plate.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

discharge coefficient; experimental; flow conditioners; flow measurement; gas; orifice meter; velocity profile

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