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## NIST Technical Note 1419

# Flowmeter Installation Effects Due to A Generic Header

T. T. Yeh and G. E. Mattingly

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# PREFACE

The research results reported in this document were produced with the support of a National Institute of Standards and Technology (NIST) initiated industry-government consortium. This is an established cooperative research effort on generic technical issues to produce industry needed flow metering improvements. In this mode of operation, there is a high degree of interaction between the representatives of the consortium member companies and the NIST researchers. These interactions include: (1) the planning of the specific focus of the NIST research efforts, (2) the discussions and analyses of the results obtained, and (3) the conclusions drawn for the particular phase of the work. For this reason, it is pertinent to acknowledge both the support given to this phase of the research program and the technical contributions made by the representatives of the consortium members.

The current consortium as of October 1993 is, alphabetically:

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15. NRTC(NOVA COR Res. Tech.Corp.)
16. Pacific Gas & Electric Co.
17. Rosemount

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# NOMENCLATURE

| | |
|---|---|
| C | The distance between the exit plane of the tube bundle flow conditioner and test meters |
| $C_d$ | $=W_b.[(\rho/(2\Delta P))(1-\beta^4)/\ \beta^4]^{1/2}$, Orifice meter discharge coefficient. |
| $C_{d.s}$ | Discharge coefficient at reference condition |
| D | Pipe diameter, 52.5 mm |
| $D_{21}$ | Displacement parameter |
| d | Hole diameter of orifice plates |
| f | Meter frequency |
| $P_6$ | Peakness parameter |
| r | Radius distance |
| Re | Reynolds number, $=W_bD/\nu$ |
| $S_a$ | A mean swirl angle, $=(\phi_+ + \phi_-)/2$ |
| St | Turbine meter Strouhal number, $fD/W_b$ |
| $S_1$ | Pipe swirl number |
| U | Mean velocity component in X direction |
| V | Mean velocity component in Y direction |
| W | Mean velocity component in Z direction |
| $W_b$ | Average bulk velocity |
| $W_c$ | Mean velocity at pipe center line |
| X | A coordinate axes in a horizontal direction |
| Y | A coordinate axes, positive in upward direction |
| Z | A coordinate axes, positive in downstream direction |
| $\beta$ | Orifice plate beta ratio, d/D |
| $\nu$ | Kinematic fluid viscosity |
| $\rho$ | Fluid density |
| $\phi_+$ | Maximum magnitude of skew angle, arctan(V/W), in positive X |
| $\phi_-$ | Maximum magnitude of skew angle, arctan(V/W), in negative X |
| $\Delta C_d$ | Change of discharge coefficient, $C_d - C_{d.s}$ |
| $\Delta P$ | Differential pressure across the orifice plate |
| $\Delta St$ | Change of turbine meter constant, $St-St_s$ |

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## ABSTRACT

This report presents recent results obtained in a consortium-sponsored research program on flowmeter installation effects being conducted at NIST-Gaithersburg, MD. The piping element tested and reported here is a generic header which has a specific arrangement of one inlet and two outlets. The results reported here are for the outlet nearest the inlet operated fully open with the other outlet fully closed. The meter performance measured in this outlet are reported with and without the installation of a conventional 19-tube concentric tube bundle flow conditioner. The LDV studies of this header piping configuration are presented in a separate report. [1]

The performance characteristics of a range of orifice meters with dimensionally scaled pressure tap geometries and a specific turbine meter are presented. The scaled orifice pressure tap arrangement is expected to set precedence for larger meter tests in that this data will be comparable to that from other research efforts where different sizes are used. The changes in discharge coefficients for orifice meters downstream of the header are : 1) positive for the smallest beta of 0.4, 2) positive but smaller for beta of 0.6, and 3) negative for the largest beta of 0.75. This header effect on orifice meter performance is similar to that found in the case of the double elbows out-of-plane configuration. The effect of angular pressure port location on orifice meter performance is not apparent from the data.

The change in Strouhal number for the turbine meter is positive for all conditions tested. This shift diminishes to zero very slowly with meter position downstream from this header. The shift is 0.4% at the position of 3.5~9.3 D downstream of the header. However, it takes about 60 pipe diameters to bring this shift down to the 0.1% level.

The tube bundle is quite effective in removing swirl from the flow in the pipe. With the 19-tube tube bundle installed, the change in turbine meter constant is within ±0.1% of the reference value for all positions tested. However, this tube bundle creates other effects such as increased turbulence level that produce pròfile evolutions that are different from those that occur without the tube bundle. These different evolutions significantly affect the orifice meters.

The correlation between the performances of these meters and several velocity profile indexes for this header are also presented. These relationships can be useful for developing criteria for improving the meter performance in non-ideal installation conditions.

## INTRODUCTION

The flow measurement community wants increased metering accuracy. In many cases, meters are being retrofitted into fluid systems that were not designed for them. This invariably means the flowmeters are being inserted into "non-ideal" installation conditions where the upstream piping elements such as elbows, etc. produce pipeflow distributions that differ from the ideal ones used to design meters. "Ideal" installation conditions are where the meter location is preceded by sufficiently long, straight lengths of constant diameter piping that the meter's performance is not affected by the meter installation position. High accuracy levels are desired for critical meter systems. Such levels can be achieved by installing meters in ideal installation conditions. When this is not possible, the nature of the non-ideal conditions should be understood together with the effects these conditions have on flow meters. This is the objective of the NIST research on flowmeter installation effects.

The NIST-initiated consortium research program on flowmeter installation effects is designed to improve fluid metering performance when installation conditions are not ideal. This program has the main objective of producing a basic understanding of the flow phenomena that are produced in prevalent non-ideal installation conditions and to quantify these phenomena relative to the pipe flow in ideal installation conditions. The experimental program is based upon the measurements of pipe flow velocity profiles from selected piping configurations using laser Doppler velocimetry (LDV) in water flow in stainless steel pipe 50 mm in diameter where the diametral Reynolds number is $10^5$. Flowmeter performance is presented in the Reynolds number range from $10^4$ to $10^5$. Orifice and turbine meters have been tested, and the effects of tube bundle flow conditioners have been assessed.

Orifice and turbine meters have been used as examples in assessing installation effects. The characteristics of these meters have been determined and analyzed to show meter manufacturers and users alike how to improve performance in non-ideal installations, such as using flow conditioning. Meter performance has been determined for different installation locations downstream of selected pipeline elements, both with and without a tube bundle flow conditioner. The results show that while the conventional 19-tube tube bundle successfully removes swirl from these pipeflows it apparently produces other effects in the streamwise velocity profiles that cause several different types of perturbations on the meter performance [2-5].

Previous phases of this research program have produced measurements of the pipeflows in the downstream piping from the configurations of a single elbow, double elbows-out-of-plane, the tee-used-as-an-elbow, the concentric reducer, and a 45° elbow. Conventional, long-radius elbows are used in these studies; the radius of the centerline through these elbows is 1.5 pipe diameters. Detailed results of these studies can be found in [6-10]; additional summary descriptions are given in [11-14].

The primary piping element used in the present report is a generic header configuration. Header or manifold configurations are commonly found in various industrial plants. One of the most common reasons to use this configuration is to improve the overall rangeability of flow rate measurements by using headers with multi-outlet meter stations. Other purposes of header configurations in multi-run meter piping are to equalize the flow in the runs or to reduce capital cost in making flow rate measurements. Headers or flow manifolds are also used to rearrange the flow loop direction or to serve as a settling chamber in designing flow loops. Despite the wide spread industrial use of headers, there is very little information available regarding the flow patterns emerging from headers or the effects of these flows on meter performance. Recently, flow disturbances caused by special headers and their effects on metering performance have been the subjects of various investigations [15,16]. However, most of the configurations used in these investigations are the combinations of the specific header and various upstream piping elements such as single elbow, reducer, riser, etc. It is known that the flow upstream of a header may greatly influence the flow pattern exiting the header. Rather than test the combination of a header with complicated or unknown upstream/downstream piping elements, the objective of the present study is to determine the meter performance in the flow pattern produced solely by the generic header. The corresponding LDV studies of the pipeflow produced by these piping configurations are reported elsewhere [1].

## TEST CONFIGURATION: A Generic Header

Figure 1 shows a sketch of the generic header geometry, that is denoted as H342. This generic header consists of one inlet and two outlets having the same pipe size. The direction of the inlet pipe is normal both to the header and to the outlet pipes. The diameters of the inlet, the header, and outlet pipes are 77 mm, 103 mm, and 52 mm, respectively. The designation "342" denotes the relative diameter ratios of 3:4:2. Other parameters needed to be specified for this header test are the flow rate ratio between the two outlets and the outlet selected for the test. For the propose of identifying a test condition, the test configuration will be denoted as H342-F1/F2-n. H342 denotes the one inlet and two outlets header. F1/F2 denotes the flow rates flowing through the outlet-1 (near) and outlet-2 (far). The last digit "n" is used to denote the outlet# in which the meter is tested. In this report the complete configuration is H342-100/0-1. That is, all flow (100%) is going through the outlet-1 and no flow is in the outlet-2 and meters are tested in the outlet-1. The test results include measurements with and without the conventional 19-tube concentric tube bundle flow conditioner. In this test the header is installed vertically and the upper outlet is the outlet-1 and the lower one is outlet-2. Although other flow divisions can be arranged, it was thought that, in this condition, the effect of header on the flow downstream will be most significant, i.e., the worst case for downstream meter performance, due to the largest possible flow rate in the outlet pipe. Figure 2 shows the piping arrangement and the coordinate system used in the test. A right handed coordinate system is used which has the system origin (i.e., X=Y=Z=0) in the entrance plane of the outlet-1 (at header tank diameter) and at the pipe centerline. The positive Z direction is downstream; the positive Y direction is upward; the X direction is therefore to the right looking upstream. D is the pipe inner diameter in the test section.

To study the flow effects produced solely by the generic header configuration, efforts have been made to ensure a fully developed pipe flow that is free from other disturbances enters the header. The upstream piping was arranged so that over 45 pipe diameters of straight, constant diameter (75 mm (3 in)) piping preceded the header. This inlet pipe section was a single piece of standard piping to assure a concentric constant diameter along the entire section without any misalignment that could result from joints. Upstream of this straight length of piping, the inlet flow was arranged to have a special, radial inlet so that no axial vorticity was produced by this entrance condition. Although the pipeflow entering the header was not directly measured, all previous LDV measurements from previous phases of our program made downstream from the single elbow showed that the effects of the elbow were negligibly small after about 30 pipe diameters for Reynolds number 100000. Since in this 75 mm (3 in) diameter pipe, the Reynolds number was 66000 (corresponding to 100000 in the 52 mm pipe), the pipeflow entering the header was assumed to be fully developed. With these reference profiles entering the header, the exiting pipeflows can be interpreted, for this conventional piping configuration, to be due solely to this generic header.

A conventional, 19-tube, concentric type tube bundle flow conditioner was also tested with the generic header. In this report the results for flowmeter performance will be presented. The results for the velocity measurements downstream of this generic header configuration are presented separately [1].

## EXPERIMENTAL RESULTS

### A) Orifice Meter Performance

Discharge coefficients were measured for selected orifice flowmeters downstream of the header configuration. A special orifice plate holder having scaled pressure taps was used in the test. Figure 3 shows a sketch of the pressure ports and the orifice plate holders for flange taps. The dimensions for conventional pressure ports for flange taps are given for both 10 cm (4 in) and 5 cm (2 in) diameter meters. The scaled ports on the 5 cm (2 in) pipe are the scaled down ( half scale ) version of the 10 cm (4 in) meter. The API standard [17,18,19] indicates that meter tubes using flange taps shall have the center of the upstream pressure tap hole placed 2.54 cm (1 in) from the upstream face of the orifice plate. The center of the downstream pressure tap hole shall be 2.54 cm (1 in) from the downstream face of the orifice plate. The tap hole diameter should be within 6.4 mm ~ 9.5 mm (0.25 in~ 0.375 in) for 5 cm (2 in) meter, and within 6.4 mm ~ 12.7 mm (0.25 in~0.5 in) for 10 cm (4 in) meter and larger.

To examine the angular effect of the pressure tap location for orifice meters in the header flow, the test data were obtained for four different angular locations. Figure 3 also shows the scaled four port orifice plate holder used in the test. The effects of pressure tap orientations on orifice meter performance can thus be determined. For this scaled plate holder, the center of the upstream pressure tap hole is placed 1.27 cm (0.5 in) from the upstream face of the orifice plate and the center of the downstream pressure tap hole is 1.27 cm (0.5 in) from the downstream face of the orifice plate. The tap hole diameter is 6.4 mm (0.25 in). It is a holder with four sets of ports scaled to be similar to the conventional flange tap arrangement for a 10 cm (4 in.) diameter meter; this is intended to give results that can be compared to those obtained from conventional 10 cm (4 in) flange-tapped meters. For the test results reported, the holder was mounted in an orientation so that two sets of the pressure ports were in the vertical plane and the other two were in the horizontal plane. The 0°, 90°, 180°, and 270° ports were located at +Y, +X, -Y, and -X directions, respectively. The orifice plate holder, which is similar to conventional orifice flanges, used three dowel pins to align the flanges properly and centering pins to hold the plate in position while bolting the flanges.

The nominal values of the beta ratio selected for the test are 0.4, 0.6, and 0.75. Each orifice meter has been tested in a different range of Reynolds numbers over a 2.5 to 1 turndown. The reference values of the test meters were measured in a fully developed pipe flow downstream of about 200 diameters of constant diameter (5 cm), straight pipe. A transfer standard flowmeter which was calibrated gravimetrically before these tests was used for all flowmeter performance tests. However, during the course of these tests of flowmeter installation effects, all conditions were maintained to be the same as those for the reference case, In this way the uncertainty arising from a systematic effect or from a common error was minimized and the actual effects due to the installation condition can be accurately determined. The estimated uncertainty of the transfer flowmeter was 0.33%. The uncertainty of the pressure measurements was 0.3%, and was 0.2% for the discharge coefficients.

Figure 4 presents the variations of the reference discharge coefficients obtained from the different sets of pressure ports for beta=0.75. The discharge coefficient was determined by $C_d=W_b.[(\rho/(2\Delta P))(1-\beta^4)/\ \beta^4]^{1/2}$, where $W_b$ is the average bulk velocity, $\beta=d/D$ is the beta ratio of the plate, $\rho$ is the water density, and $\Delta P$ is the differential pressure across the orifice plate. The reference $C_d$ was measured in a fully developed pipe flow downstream of about 200 diameters of constant diameter, straight pipe. In the figure, all data are normalized by the averaged discharge coefficients obtained from all four ports of the 4-port scaled holder. These data show that the variations are normally very small and within about ± 0.15% which is considered within the uncertainty of the experiments of 0.2%. The variations for the two smaller beta ratios are smaller. These data indicate that the reference values for all four sets of scaled ports are practically the same. Thus the averaged value from these four references could be chosen as a common reference value in determining the amount of the installation effect for all pressure ports. As discussed in the 45 degree elbow case, [6] the discharge coefficients for the conventional ports and the scaled ports could be different. Because of the variations of the wall pressure along the pipe, the differential pressure and thus the discharge coefficients obtained from the various pressure tap locations can be different. The effect of pressure tap separation on the discharge coefficients had been documented in various references [18,20,21]. In 1990, the American National Standard Institute adopted a new empirical equation, known as the RG equation, for determining discharge coefficient [18]. The RG equation has included the effects of the tap location on the empirical coefficient of discharge equation for orifice meters.

The present scaled data of the 5 cm (2 in) meters are intended to compare with the data for the conventional 10 cm (4 in) diameter meters. This metering arrangement is expected to lead to precedents for larger meter tests. These precedents could be that larger meter results may be able to be successfully predicted using smaller meters tested in quicker, cheaper tests. At each test condition the discharge coefficients at four port locations were measured. The range of Reynolds number spanned is 20000 to 100000; the beta ratio range is 0.40 to 0.75 and each meter is tested over a 2.5 to 1 turndown.

### a. Downstream of a Generic Header.

The orifice flowmeter performance data downstream of the generic header piping configuration, H342-100/0-1, are presented in tabular format in Appendix A. The graphic presentations are discussed here.

Figure 5 shows the change in discharge coefficients for a $\beta = 0.4$ orifice meter at Z=4.66 D downstream of the header, H342-100/0-1 as a function of Reynolds number. At each flow rate there are five data points taken. Both the individual data points and the averaged data from the five individual data are shown. In addition, all data from four angular pressure port locations are presented. Figures 6 and 7 show the similar data for $\beta = 0.6$ and 0.75, respectively. These data clearly show significant installation effects on the meter discharge coefficients for the three orifice meters tested. The changes in discharge coefficients are positive for the smallest beta of 0.4, are also positive but smaller for beta of 0.6, and are negative for the largest beta of 0.75. This kind of effect has been found in the case of double elbows out-of-plane configuration [6,12]. There are many flow effects that can affect the performance of a flowmeter. Here two of them can be attributed to the final change in the discharge coefficients :1) swirl flow (transverse velocity profile) and 2) axial velocity profile. Swirl flow will normally result in an increase in the discharge coefficient, due to centrifugal effects. A uniform axial velocity profile will tend to decrease the coefficient, due to the increased pressure drop across the orifice plate required to move the additional fluid near the wall through the orifice hole, which is located at the center of the orifice plate. The final result thus depends on the competition of the intensities of these two effects.

These data also show that discharge coefficients tend to increase with Reynolds number, thus indicating that the effects of swirl flow increase as the flow rate increases. Less apparent is the effect of angular position on discharge coefficient. The variation of the change in discharge coefficients is smaller than the data uncertainty indicated by the individual data points. Since the effect of angular tap location is smaller, the data presented below will only be for those averaged data obtained at the 0° pressure port. The data for all four angular pressure ports are given in Appendix A.

Figure 8 presents the percentage change in discharge coefficient for a $\beta = 0.4$ orifice meter installed at different downstream positions from a header, H342-100/0-1, for a range of Reynolds numbers between 20000 and 60000. These are averaged data obtained from the scaled ports at the 0° angular position ( at +Y direction). The ordinate in the figure is the percentage shift at each flowrate, in discharge coefficient relative to that obtained for the reference condition. Similar data for $\beta = 0.60$ and 0.75 are shown in Figures 9 and 10, respectively. The changes in discharge coefficients are positive for the smallest beta of 0.4, are also positive but smaller for beta of 0.6, and are negative for the largest beta of 0.75. The discharge coefficients increase with Reynolds number. These data indicate that the effect of swirl flow increases as the flow rate increases. For all cases, the change in discharge coefficients is largest for meters at the nearest position of Z/D=4.66. The magnitude of these changes decreases as the distance increases. The changes in discharge coefficient are practically zero at about Z/D=51.

Figures 11-13 show the change in orifice meter discharge coefficients as a function of meter location downstream from the header H342-100/0-1 for each beta ratio. In each figure data for three Reynolds numbers(lowest, medium, and highest test flows) are given. The ± 0.2% error bars indicating the typical uncertainty are also shown. Figure 11 is for β = 0.40 and Re = 22000, 36000, and 55000. The changes in discharge coefficients are all positive. The largest positive shift is about 4.6% for Z/D = 5 and Re = 55000. These changes decrease as the distance increases. At Z/D= 45 and beyond , the shifts are within ± 0.2%. Similar results are found for the medium orifice plate, β = 0.60 as shown in Figure 12. The shift is positive except that the magnitude is smaller than that of β = 0.4. Figure 13 is for the largest beta orifice plate tested, with β = 0.75. As contrasted with the results of the smaller beta plate, the shift for β = 0.75 is negative. As the distance increases the negative shift is reduced. The shift is reduced to within the ±0.2% when the distance, Z/D, reaches about 22 for Re = 44000 and about 40 for Re=99000.

Figure 14 compares the change in discharge coefficients as a function of meter location downstream from the header H342-100/0-1 for three beta ratios at the same Reynolds number of Re=55000. These show sizeable differences that depend upon beta ratio. In contrast to the usual result that the larger beta ratio produces a larger coefficient shift, these data show that the smallest beta ratio produces a larger coefficient shift. The different results are partly due to the fact that swirl has more effect on the small beta orifice meter while the axial profile flatness has more effect on the larger beta orifice meter. The change in discharge coefficient is largest for installation positions near the header with positive shifts of 4.6% for the smallest beta ratio of 0.4 and negative shifts of -1.9% for the largest beta ratio of 0.75. For meter installations more distant from this header, the magnitudes of the shifts diminish slowly. It is noted that, although the shift could be either positive or negative depending on the size of beta ratio, the change in orifice discharge coefficient condition prevails for extended lengths downstream of the header and the orifice meter requires about 45 diameters of downstream distance before discharge coefficients attain values equal to those for the fully developed pipeflow conditions.

### b. Downstream of a Header with a 19-Tube Tube Bundle

Figure 15 shows the sketch of the header configuration and the 19-tube tube bundle installation location. During the complete tube bundle test, the bundle is installed at a fixed location relative to the header. The upstream and downstream ends of the tube bundle are at Z/D=4.26 and 6.2, respectively. Again Z is the axial distance downstream from the exit plane of the header. The distance between the exit plane of the tube bundle flow conditioner and test meters is denoted by the length, C. Thus, in the present test, Z/D-C/D = 6.2. The tube bundle used is a conventional 19-tube concentric design and its arrangement is also shown in figure 15. The unit is a geometrically scaled version of the prevalent unit used in large pipe sizes according to orifice meter technology, [16]. It is comprised of tubes having a diameter of 9.5 mm, wall thickness of 0.4 mm, and tube length of 101.6 mm (approximately 2D length).

The orifice meter performance downstream of the header, H342-100/0-1 with the 19-tube tube bundle is reported in this section. The changes in orifice meter discharge coefficient are presented in tabular format in Appendix B. For all tests, the orifice plate data are obtained using the same scaled ports holder shown in Figure 3.

Figure 16 shows the change in discharge coefficients for a beta=0.75 orifice meter installed at Z= 8.92 D and C= 2.72 D downstream of the header, H342-100/0-1, and the 19-tube tube bundle as a function of Reynolds number. The discharge coefficients from the pressure ports at the four angular orientations (0°, 90°, 180°, and 270°) were measured. Again the pressure taps are those scaled to conventional 10 cm (4 in) diameter meters. At each flow rate, both the five individual data points (shown by symbols) and the averaged value (shown by curve) are given. The data indicate that, qualitatively, there are differences for different angular tap locations. However, these differences are much smaller than the change due to the piping configuration itself. The effect due to angular tap location is of the order of .5% of the discharge coefficient, while that due to the piping configuration could be as much as 3%. In addition, the variation of the change in discharge coefficients due to angular tap location is smaller than the data uncertainty of ±0.2% as indicated by the individual data points. Since the effect of angular port locations is smaller, the data presented below will only be for those averaged data obtained at the 0° port. The complete data for all four pressure ports are given in Appendix B.

Figures 17-19 show the change in discharge coefficients at different downstream positions from the header, H342-100/0-1 and the 19-tube tube bundle as a function of Reynolds number. Figures 17, 18 and 19 are for beta ratio =0.4, 0.6 and 0.75 with the corresponding Reynolds number ranges of 25000 to 55000, 35000 to 85000 and 45000 to 100000, respectively. The same data are also plotted differently in figures 20-22, to show the change in discharge coefficients versus location downstream from the header, H342-100/0-1 with the 19-tube tube bundle located at Z= 6.2 D. In these figures, data for three flow rates are shown for each beta ratio. The change in discharge coefficient for all three beta ratios is shifted downwardly at the locations close to the tube bundle. The data in the previous section show that without the tube bundle, the changes in discharge coefficient are positive for the smallest beta ratio while the changes are negative for the largest beta ratio. This indicates that the tube bundle is quite effective in removing the swirl flow in the pipe. However, the tube bundle produces other effects on orifice meter performance. Figures 20-22 show the typical change in orifice meter discharge coefficient with distance downstream of a tube bundle flow condition: the value downshifted at closer locations, followed by a cross-over to a positive shift, and then returning to zero as the distance increases.

Figure 23 compares the results for three beta ratios of 0.4, 0.6, 0.75 for change in discharge coefficient plotted against the axial distance from the tube bundle locations, C/D, upstream of the meter for Re=55000. These results show clearly the dependence of the orifice characteristics for the three meters at the same flowrate. Significant negative shifts in discharge coefficient are noted especially for the larger beta ratios; the magnitudes of these shifts diminish with increasing axial separation, C, between the orifice plate and the tube bundle exit. All three beta ratio meters achieve about the same zero shift positions of 12~14 D. If one places a tolerance of ± 0.2% about the reference orifice discharge coefficient, the meter performance for beta = 0.4 is acceptable for C/D > 9, and for beta = 0.6, it is acceptable for C/D > 11. The performance for beta = 0.75 is only acceptable when the 19-tube tube bundle is located at a C/D within the range of 12~14 with the cross over point at about C/D = 13 and C/D > 40.

### c. Comparison of Orifice Meter Performance

Since the present header pipe flow is very similar to the pipe flow produced by a closely coupled double elbows out-of-plane configuration [1,6,12 ] the meter performance for the header flow is expected to be very similar to that of the double elbows case. The meter performance for the header flow with and without the tube bundle is compared with the previous data of a closely coupled double elbows out-of-plane. The changes in discharge coefficients downstream from three different piping configurations are compared: 1) Header, H342-100/0-1 alone, 2) Closely coupled double elbows out-of-plane, and 3) H342-100/0-1 with a 19-tube tube bundle. Figure 24 shows the change in discharge coefficient as a function of the axial distance, Z for the smallest beta downstream from those three different piping configurations. The data show the change in discharge coefficients for both the header flow and the double elbows out-of-plane are positive with the magnitude of the shift much larger for the header case. The shift in discharge coefficient for the header with tube bundle is negative at about -0.5% for the closest location of Z/D = 8. As we have learned before, swirled flows will make the discharge coefficient increase, while the flatness of the axial velocity profile will make the coefficient decrease. The net result of these two effects on the meter performance is shown on the figure. That is, the swirl effect is larger than the flatness effect for both the header and double elbow out-of-plane flows. Also the effect of the swirl flow on the discharge coefficient is largest for the header without a tube bundle, and is smallest for the header with a 19-tube tube bundle. This is consistent with the result of the swirl number reported [1]. The data seem to confirm that the header produces a more energic swirl flow than the double elbows out-of-plane. The tube bundle is very effective in reducing the swirl flow. Figures 25 and 26 show the comparisons of the change in discharge coefficients for the medium and larger beta ratios. For the medium beta ratio shown in the Figure 25, the shifts in coefficients for the header and the double elbows out-of-plane are still positive although they are smaller than the shifts for the small beta case. The shift for the header is still larger than those for the double elbows out-of-plane case. The largest downshift in the coefficient for the header with the tube bundle is about -1.6%, larger than those for the smaller beta as shown in Figure 24. Figure 26 shows the data for the largest test beta of 0.75. For all three configurations, the shift in coefficients are all negative at closer locations. These seem to indicate axial velocity profiles are more influential on the meter performance than the swirl flow effects for the largest beta ratio.

## B) Turbine Meter Performance

As for the orifice meters, the performance of a turbine meter was also assessed in the two types of arrangements: header H342-100/0-1 without and with the 19-tube tube bundle flow conditioner. In each case the turbine meter performance was determined at various axial locations downstream of the header. The transfer standard was used for all these flowmeter performance tests. As in the orifice meter tests, during the course of turbine meter tests, all conditions were maintained at the same conditions as those for reference case. In this way, the actual effects due to any installation condition can be accurately determined. The estimated uncertainty of the meter constant was 0.1%. The complete data for the change in meter constants are given in Appendix C.

Figures 27-28 present the percentage change in Strouhal number for a turbine meter at different downstream installation positions from a header as a function of Reynolds number. The meter factor is given by the Strouhal number, $St = fD/W_b$, where f is the meter frequency, D is pipe diameter, and $W_b$ is the averaged bulk velocity. The ordinate is the percentage shift in meter factor at each flowrate taken relative to the reference condition. Here the reference Strouhal number of the turbine meter was measured in a fully developed pipe flow downstream of about 200 diameters of constant diameter, straight pipe. Figure 27 is for the header alone and figure 28 is for the header with the 19-tube tube bundle. The data shows results over the Reynolds number range from 40000 to 100000. Figures 29 and 30 present the meter performance as a function of axial distance for three Reynolds numbers of 44000, 72000 and 99000. The difference in the change in Strouhal number among the three Reynolds numbers is considered small with and without the 19-tube tube bundle. For the header alone, the change in Strouhal number for the turbine meter is positive. The shift is 0.4% for the installation position 3.5~9.3 D downstream of the header. This shift approaches zero for the furthest downstream test position of Z= 61.62 D. If one places a tolerance of ± 0.1% about the reference meter constant, the minimal pipe length required to ensure an acceptable meter performance for the turbine meter is about 60 pipe diameters.

When the turbine meter is tested downstream of the header with the 19-tube tube bundle, results are as given in figure 30. The data show the meter factor shift is less than 0.1% for all installation positions of the 19-tube tube bundle. That is, this turbine meter is not affected by the pipeflows exiting from the combination of the header and the 19-tube tube bundle. It is, therefore, concluded that the geometry of this turbine design is capable of successfully averaging over the flow patterns presented in the header with a 19-tube tube bundle and producing a meter factor that is essentially the reference value in these installation conditions.

## C) Correlation of Axial Velocity Profile Index and Meter Performance

Different piping configurations produce different velocity profiles. These velocity profiles can significantly affect flowmeter performance. Based on the measured velocities, important flow field parameters can be defined and quantified. Depending on the particular piping configuration some parameters may be more important than the others in affecting meter performance. Previous research results have shown that swirling flows produced by several different pipe configurations can have very strong effects on the meter performance of selected meters [2,6,11,13].

The results of velocity measurements for these piping configurations and its profile indexes are presented in an early report [1]. Various parameters can be used to characterize the pipe flows [1,22-25]. Here, four velocity profile indexes will be discussed: swirl angle, swirl number, degree of profile peakness, and a displacement parameter. The swirl produced by the header configurations is quite similar to those of the double elbows out-of-plane configuration. It is noted that there is only one large swirl eddy produced in the header configuration, as there was in the case of the double elbows out-of-plane. As shown in Ref. [1], a mean swirl angle, $S_a$, can be defined as

$$S_a = (\phi_+ + \phi_-) / 2 , \qquad (1)$$

where $\phi$ = arctan (V/W) is the vertical inclination angle of the velocity vector and subscripts + and - are, respectively, for the maximum magnitudes of $\phi$ in the positive and negative X directions along the horizontal diameter at a given axial location Z.

The decay of swirl flows can also be quantified by a pipe swirl number defined as follows:

$$S_1 = 4 \int_{-0.5}^{0.5} \frac{WVX \mid X \mid}{W_b^2 \, D^2} \, d(X/D) \ . \qquad (2)$$

The swirl number, $S_1$, corresponds to an integral of the angular momentum over the entire pipe cross-section.

The degree of peakness of the axial velocity profiles produced by the piping configurations can be quantified by $P_6$ as:

$$P_6 = \int_{-0.5}^{0.5} (W_c^2 - W^2)\, d(r/D) \bigg/ W_b^2 \,, \tag{3}$$

where $W_c$ is the velocity at the pipe center line location. The integrated quantity is similar to the momentum thickness parameters commonly used in studying boundary layer flows.

A parameter quantifying how the flow is displaced from the center of the pipe can also be useful. A more "peaky" flow at the pipe center means the flow is more concentrated at or less displaced from the pipe centerline. A displacement parameter is thus introduced to quantify the average flow displacement from the pipe centerline for a selected quantity as follow:

$$D_{21} = \frac{\int_{-D/2}^{D/2} W^2 r^2 \, dr}{D \int_{-D/2}^{D/2} W^2 r \, dr} \,. \tag{4}$$

$D_{21}$ is for the first radial moment of the dynamic pressure $W^2$. Thus, if a profile is flatter than the ideal profile the change of the peakness will be negative. In this case, the flow field is displaced away more from the center line and the change of the displacement should be positive. On the other hand, if the change of the peakness is positive, or the change of the displacement is negative, the axial mean velocity profile is more peaked at the pipe center. The detail variations of the profile indexes as a function of the distance downstream of the header flow are given in Ref.[1].

Having the distribution data as functions of the distance downstream from the header for both the orifice meter performance and the flow profile indexes we can obtain the correlations between them. Figures 31-36 show the relationships, as described in the captions, between the changes in meter performance and the parameter indexes.

Figure 31 shows the relationship between the change in discharge coefficients and the swirl number $S_1$ for all three beta ratios. A similar relationship based on the swirl angle $S_a$ is shown in figure 32. These data show at the condition of greatest swirl, in which $S_1 = -0.115$ and $S_a = 16.6^\circ$, the change in discharge coefficient has a maximum positive value of 4.7% for beta=0.4, 2.5% for beta=0.6, and a negative value of -0.08% for beta=0.75. All these shifts are diminishing as the swirl intensity is decreasing. The shifts practically reach zero at swirl number $S_1$= -0.065 and swirl angle $S_a$= 9.5°. It should be noticed that we should not conclude from these data that any flow with swirl angle $S_a$ <9.5° will produce an ideal discharge coefficient. This is because the swirl number or the swirl angle is not the only parameter that will affect the performance of the flow meter. In general, additional flow index parameters could also be important. Figures 33 and 34 show the relationships for the profile peakness, $P_6$ and the profile displacement, $D_{21}$. These data show the effect of profile peakness on meter performance. Since both the profile peakness and the swirl flow exist in the header flow and both parameters seem to be important for the orifice meter response, the measured change in coefficient for the header flow will depend on both these parameters. A simple single parameter relationship alone will not be able to predict the meter performance very well. A two-parameter or multiple-parameter model is thus required for a complete prediction. Nevertheless, the single parameter relationship is useful for any given piping configuration.

Figure 35 shows the relationship between the change in the turbine meter constant Strouhal number, St , and the swirl number $S_1$. Figure 36 shows a similar relationship for the swirl angle $S_a$. These data indicate there is a strong relationship between the swirl number $S_1$ or the swirl angle $S_a$ and the $S_t$ change. A larger swirl flow (larger magnitude of either $S_1$ or $S_a$) will produce a larger shift in the turbine meter constant $S_t$. The installation effects of the turbine meter downstream of the header seem to be dominated by the parametric features of the header swirl flow. Thus the $S_t$ value for header installations could be corrected somehow according to a single parameter empirical curve, such as the $S_1$ vs St or $S_a$ vs St curve.

## SUMMARY AND CONCLUSIONS

The meter performances of selected orifice meters and a turbine meter downstream of the generic header, H342-100/0-1, both with and without a 19-tube tube bundle flow conditioner, are reported. In this report, all flow (100%) passes through outlet-1 and no flow exits outlet-2 and meters are tested in the outlet-1. The corresponding LDV studies of the pipeflow produced by these piping configurations show these pipeflows to be similar to those from the double elbows out-of-plane configuration.[1]

A special orifice plate holder with pressure taps that geometrically scales to a 4 inch, flanged tapped meter was used in the 5 cm (2 in) orifice meters. This is done so that the 5 cm (2 in) scaled tap orifice data can be compared to conventional 10 cm (4 in) diameter meter data. This arrangement is expected to set a precedent for larger meter tests. The nominal values of the beta ratio selected for test are 0.4, 0.6, and 0.75. Each orifice meter has been tested in a different range of Reynolds numbers over a 2.5 to 1 turndown.

The data clearly show significant installation effects on the meter discharge coefficients for the three orifice meters tested. The changes in discharge coefficients are positive for the smallest beta of 0.4, are also positive but smaller for beta of 0.6, and are negative for the largest beta of 0.75. This installation effect is similar to that found in the case of double elbows out-of-plane configuration, as the secondary flow produced by the header is very similar to that of double elbows out-of-plane. At least two flow effects can be attributed to the final change in the discharge coefficients: 1) swirl flow and 2) axial velocity profile . Swirl flow will normally result in an increase in the discharge coefficient, due to centrifugal effects. A uniform axial velocity profile will tend to decrease the coefficient, due to the increased pressure drop across the orifice plate required to move the additional fluid near the wall through the orifice hole. The final result thus depends on the competition of the intensities of these two effects. These data also show the discharge coefficients are increasing with the Reynolds number, which indicate that swirl effects increase as the flow rate increases.

The effects of pressure tap orientation on orifice meter performance has also been examined. Results show there are differences for different tap locations. However, these differences are smaller than the change due to the header flow itself. The effect due to angular tap location is of the order of 0.5% of the discharge coefficient, while that due to the header is as much as 4%.

The tube bundle is quite effective in removing the swirl flow in the pipe. However, it also creates other effects on the orifice meters. The changes in discharge coefficients for orifice meters downstream of the header with 19-tube tube bundle have significantly reduced values for installations nearer to the tube bundle. These negative shifts are reduced with distance to positive values. These reach a maximum and then diminish to zero with distance downstream. This is a typical response curve for the discharge coefficient of a orifice meter downstream of a 19-tube tube bundle.

For the header alone, the change in Strouhal number for the selected turbine meter is positive for all conditions. The shift diminishes to zero very slowly as the installation distance increases. The shift is 0.4% for the installation position 3.5~ 9.3 D downstream of the header. However, it takes about 60 pipe diameters of downstream distance to reduce this shift to about 0.1% level.

The change in meter constant for the turbine meter downstream of the header with a 19-tube tube bundle is within ±0.1% of the reference value for all positions tested. That is, this turbine meter is not affected by the pipeflows exiting from the combination of the header and the 19-tube tube bundle.

## REFERENCES

[1] Yeh, T.T. and Mattingly, G.E.; Laser Doppler Velocimeter Studies of the Pipeflow Produced by a Generic Header. NIST Technical Note 1409, April, 1995.

[2] Mattingly, G.E. and Yeh, T.T.; NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects: Report of Results for the Research Period Nov. - May 1989, NISTIR 4310, April, 1990.

[3] Mattingly, G.E. and Yeh, T.T.; Effects of Pipe Elbows and Tube Bundles on Selected Types of Flowmeters, Journal of Flow Measurements and Instrumentation, Vol. 2, pp. 4-13, January, 1991.

[4] Mattingly, G.E. and Yeh, T.T.; NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects: Report of Results for the Research Period May 1989 - Feb. 1990: Tube Bundle, NISTIR 4751, Nov. 1990.

[5] Mattingly, G.E. and Yeh, T.T.; Effects of Non-Ideal Pipeflows and Tube Bundles on Orifice and Turbine Meters, Flow Measurement and Instrumentation Journal, Special Issue on Flowmeter Installation Effects, Butterworth Publ., Guildford, U.K., Feb. 1991, pp. 1-19.

[6] Mattingly, G.E. and Yeh, T.T.; NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects: Report of Results for the Research Period July - December 1987. NISTIR-88-3898, May 1988.

[7] Mattingly, G.E. and Yeh, T.T.; NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects: Report of Results for the Research Period Jan. - July 1988, NISTIR-89-4080, April 1989.

[8] Mattingly, G.E. and Yeh, T.T.; NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects: Report of Results for the Research Period Feb-Dec. 1990: Tee Used As An Elbow, NISTIR 4753, December 1990.

[9] Mattingly, G.E. and Yeh, T.T.; Summary Report of NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects With Emphasis on the Research Period January-September 1991: The Reducer, NISTIR 4779, December 1991.

[10] Yeh, T.T. and Mattingly, G.E.; Summary Report of NIST's Industry-Government Consortium Research Program on Flowmeter Installation Effects: The 45° Elbow. NIST Technical Note 1408, Sept. 1994.

[11] Mattingly, G.E., Yeh, T.T., Robertson, B., and Kothari, K.; NBS Research on In-Situ Flowmeter Installations, Procs, AGA Distribution and Transmission Confr. Las Vegas NV, May 1987.

[12] Yeh, T.T. and Mattingly, G.E.; Mixing Motions Produced by Pipe Elbows, NISTIR 89-4029 January 1989.

[13] Mattingly, G.E. and Yeh, T.T.; Flowmeter Installation Effects Due to Several Elbow Configurations, Proceedings of the 2nd International Symposium on Fluid Flow Measurement, pp. 271-283, June, 1990.

[14] Mattingly, G.E. and Yeh, T.T.; Elbow Effects on Pipe Flow and Selected Flow Meters. Proceedings of the 6th International Conference on Flow Measurement, Korea Research Institute of Standards and Science. 1993, pp.149-167.

[15] Harbrink, B., Zirnig, W., Hassenpflug, H., Kerber, W., and Zimmermann, H.; The Disturbance of Flow Through an Orifice Plate Meter Run by the Upstream Header, 5th International IMEKO=Conference on Flow Measurement FLOMEKO, Dusseldorf (FRG), pp. 75-90, October, 1989.

[16] Williamson, I.D., Botros, K.K. and Price, G.R.; Flow Characteristics and Orifice Meter Error Caused by Upstream Headers in Multi-Run Meter Stations. The Forum on Fluid Measurements and Instrumentation of the 1993 ASME Fluids Engineering Division, June, 1993.

[17] Orifice Metering of Natural Gas and other Related Hydrocarbon Fluids, ANSI/API 2530, AGA Report No.3, 2nd Ed., American Gas Association, Arlington, VA, May 1985.

[18] Orifice Metering of Natural Gas and other Related Hydrocarbon Fluids, Part 1, General Equations and Uncertainty Guidelines, AGA Report No.3, API 14.3, GPA 8185-90, 3rd Ed., October 1990.

[19] Orifice Metering of Natural Gas and other Related Hydrocarbon Fluids, Part 2, Specification and Installation Requirements, AGA Report No.3, API 14.3, GPA 8185-90, 3rd Ed., February 1991.

[20] Measurement of Fluid Flow by Means of Orifice Plates, Nozzles, and Venturi Tubes Inserted in Circular Cross-section Conduits Running Full, ISO 5167 - 1980 (E), International Organization for Standardization, Geneva, 1980.

[21] Fluid Meters- Their Theory and Applications 6th ed, ASME, New York, 1971, ed. by Bean, H.S., Chapter I-5.

[22] Yeh, T.T. and Mattingly, G.E.; Pipeflow Downstream of a Reducer and Its Effects on Flowmeters. Flow Meas. Instrum., 1994 Vol.5, no. 3, pp.181-187

[23] Klein, A.; Review: Turbulent Developing Pipe Flow. J. of Fluids Engineering, June 1981, Vol.103, pp. 243-249.

[24] Klein,A.; Review: Effects of Inlet conditions on Conical-Diffuse Performance. J. of Fluid Engineering, June 1981, Vol. 103, p. 250

[25] Ghazi, H.S.; A Pressure Index for Predicting the effect of Flow Profiles on Orifice Meter Performance. J. of Basic Engineering, March 1966, pp. 93-100.

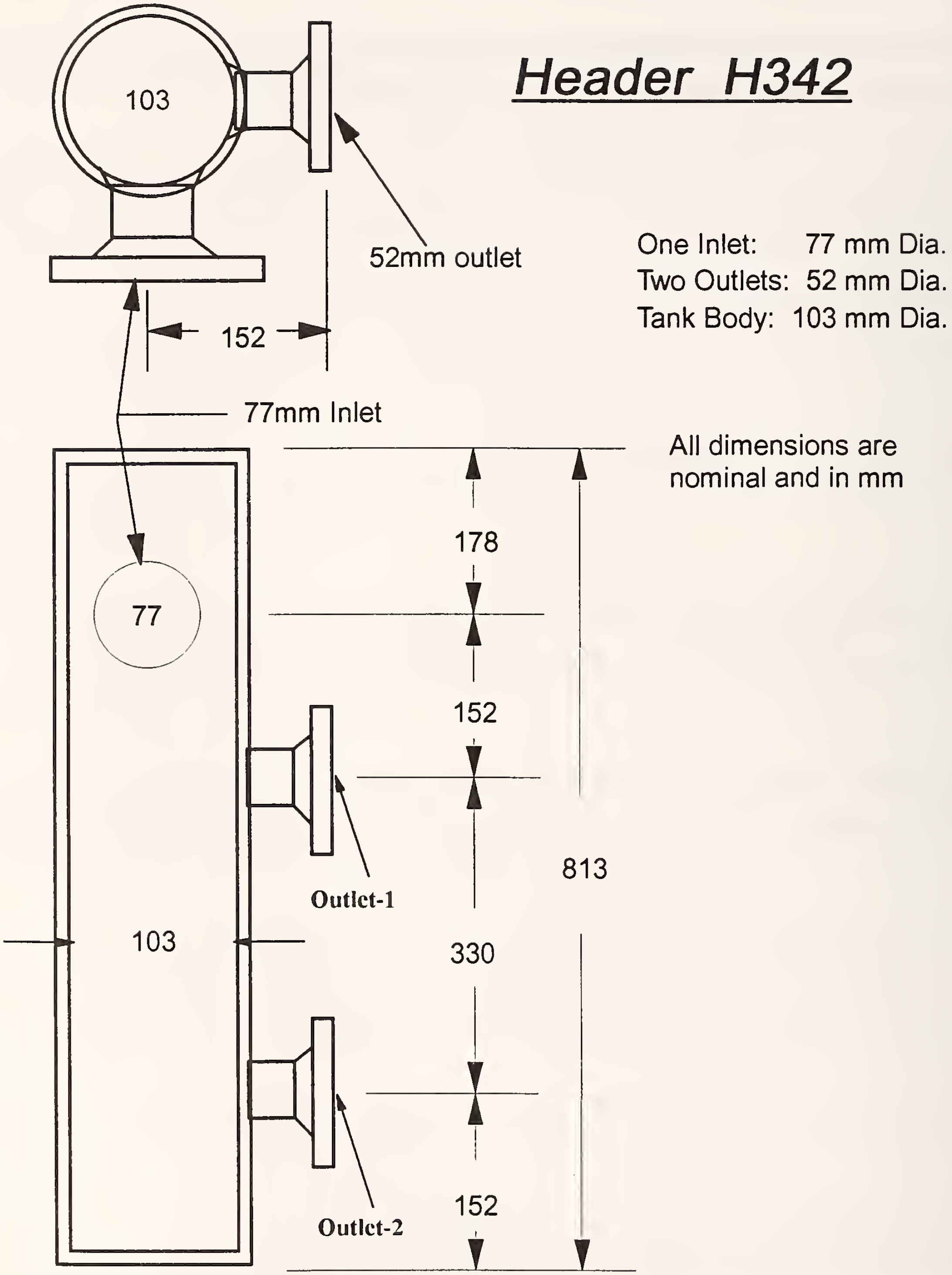


Figure 1. The Generic Header Geometry, H342 Consisting One Inlet and Two Outlets.

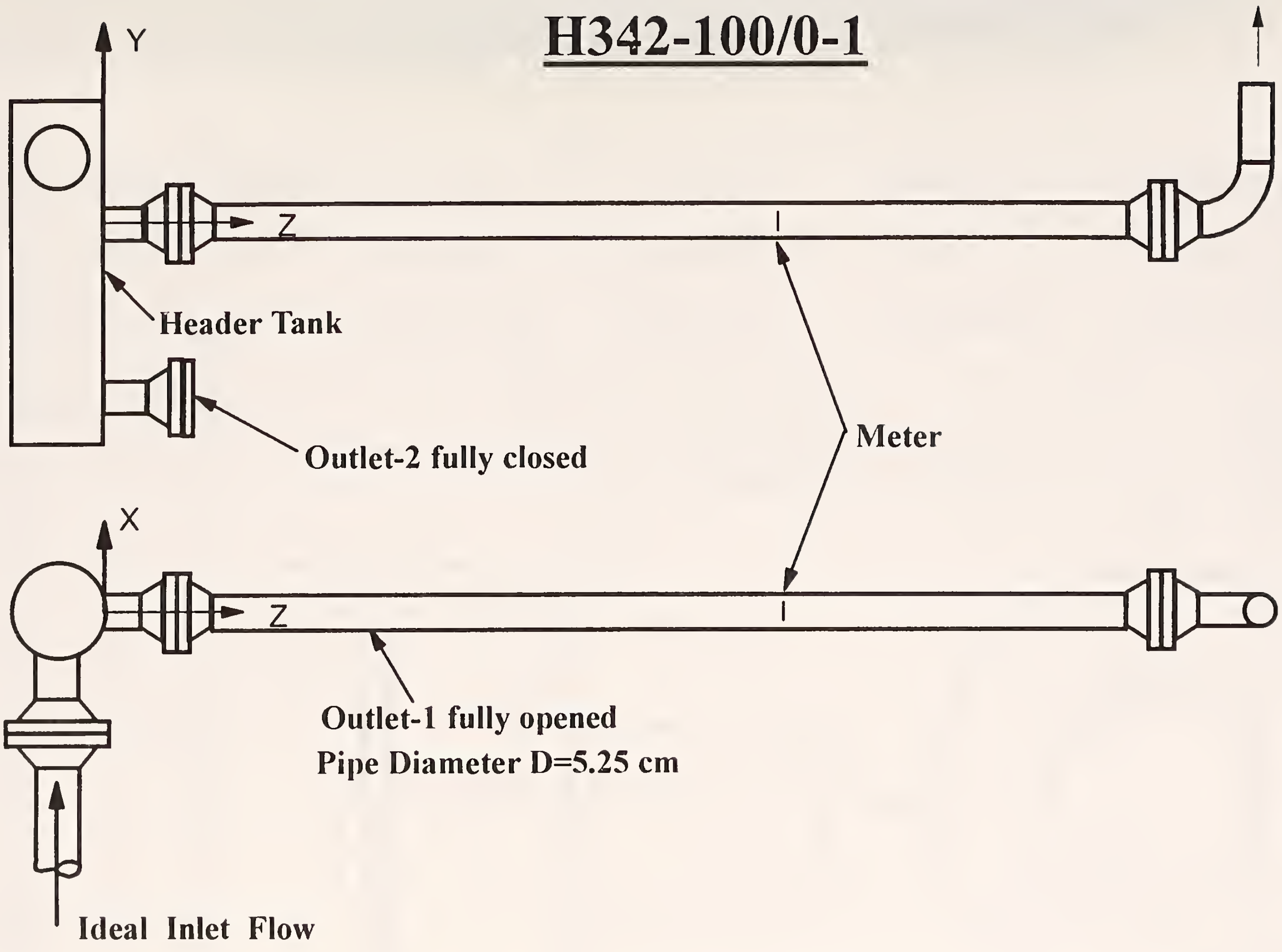
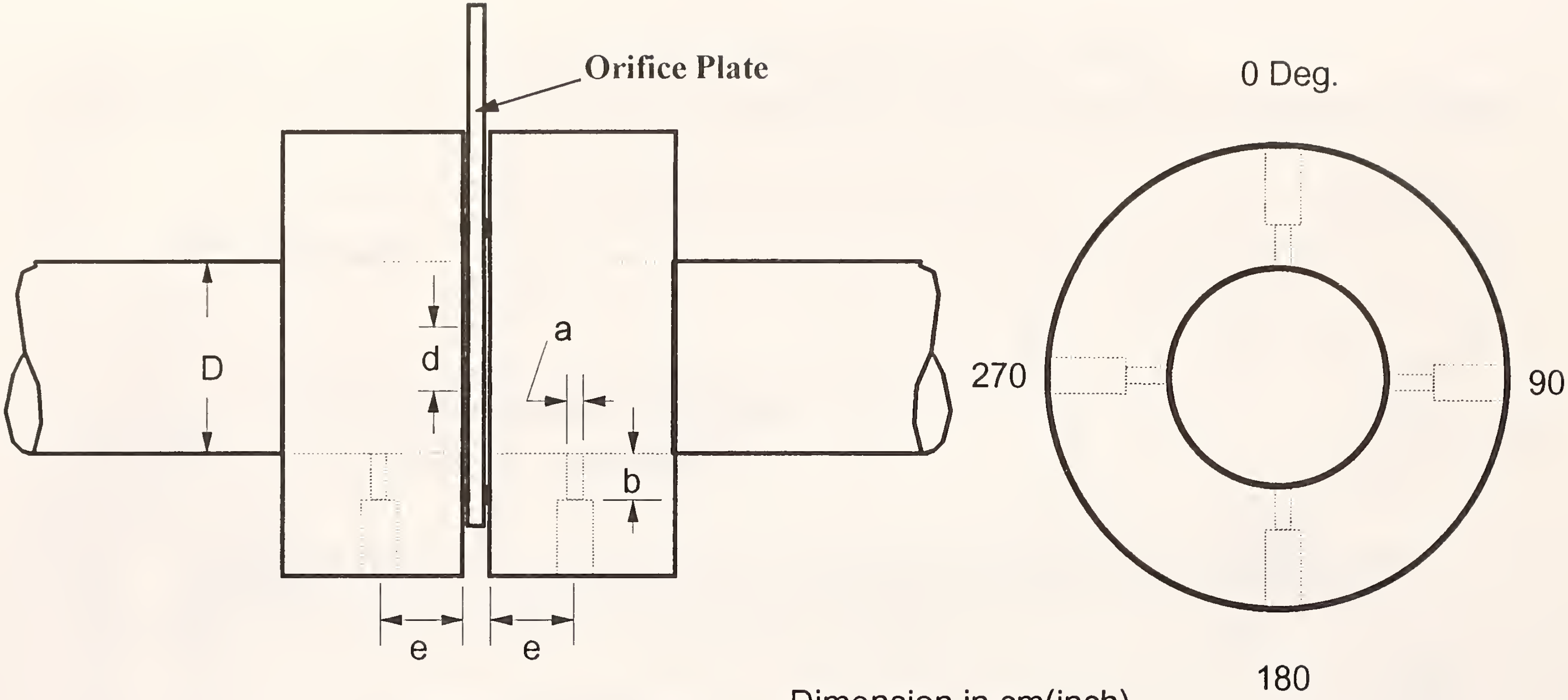


Figure 2. Sketch of the Header Arrangement and Coordinate System with the Near Outlet Fully Opened and the Far Outlet Fully Closed.



Dimension in cm(inch)

| Orifice Plate Holder | D | e | a | b |
|---|---|---|---|---|
| 10cm(4") Meter, Conv. | 10.23(4.025) | 2.54(1.0) | 1.26(0.495) | 4.76(1.875) |
| 5cm(2") Meter, Conv. | 5.26(2.07) | 2.54(1.0) | 0.95(0.375) | 2.86(1.125) |
| 5cm(2") Meter, Scaled | 5.26(2.07) | 1.27(0.5) | 0.64(0.25) | 2.38(0.9375) |

**Figure 3.** **Sketch of The Orifice Plate Holder and Pressure Ports.**

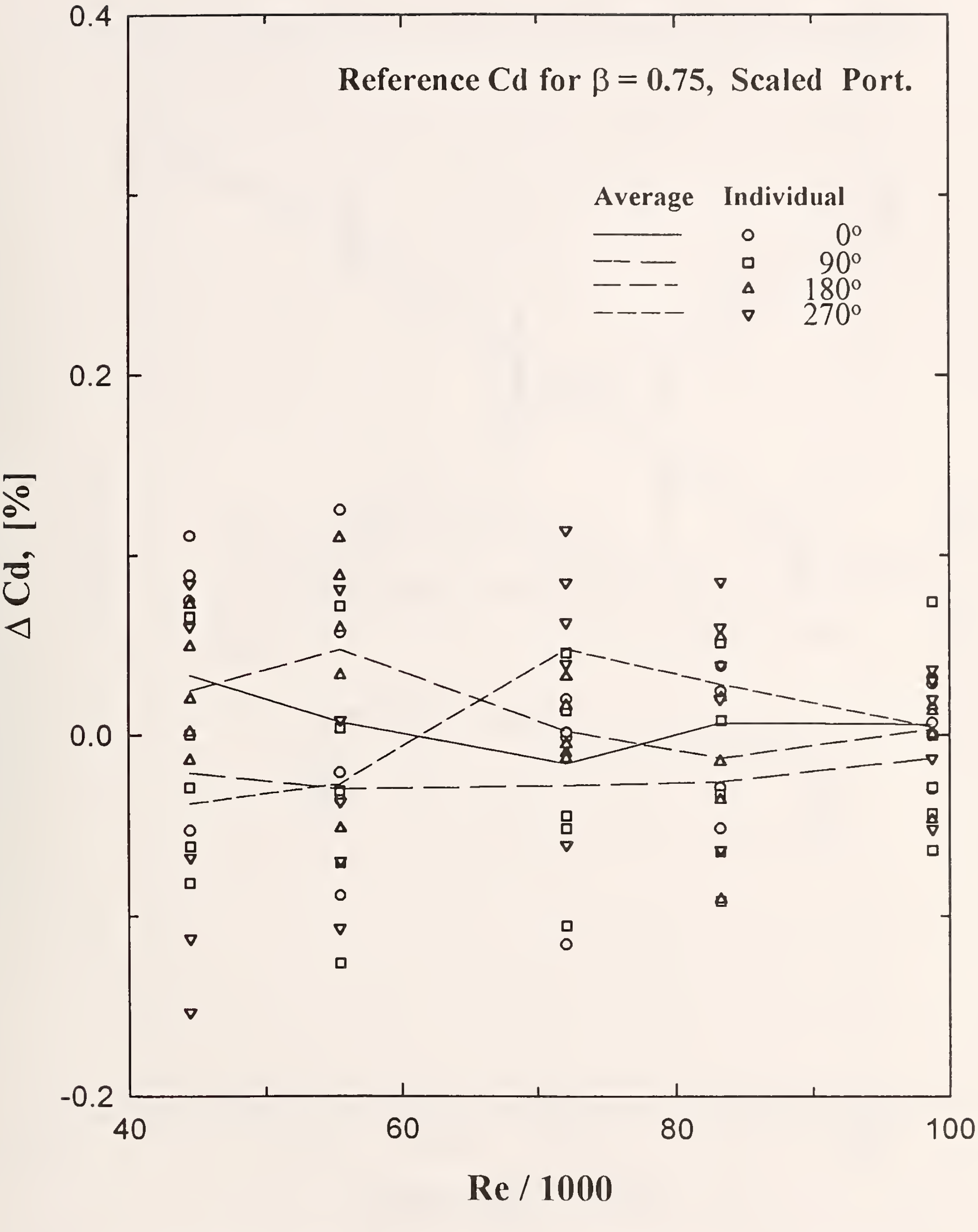


**Figure 4**. Typical Uncertainty and Angular Variation on Discharge Coefficients.

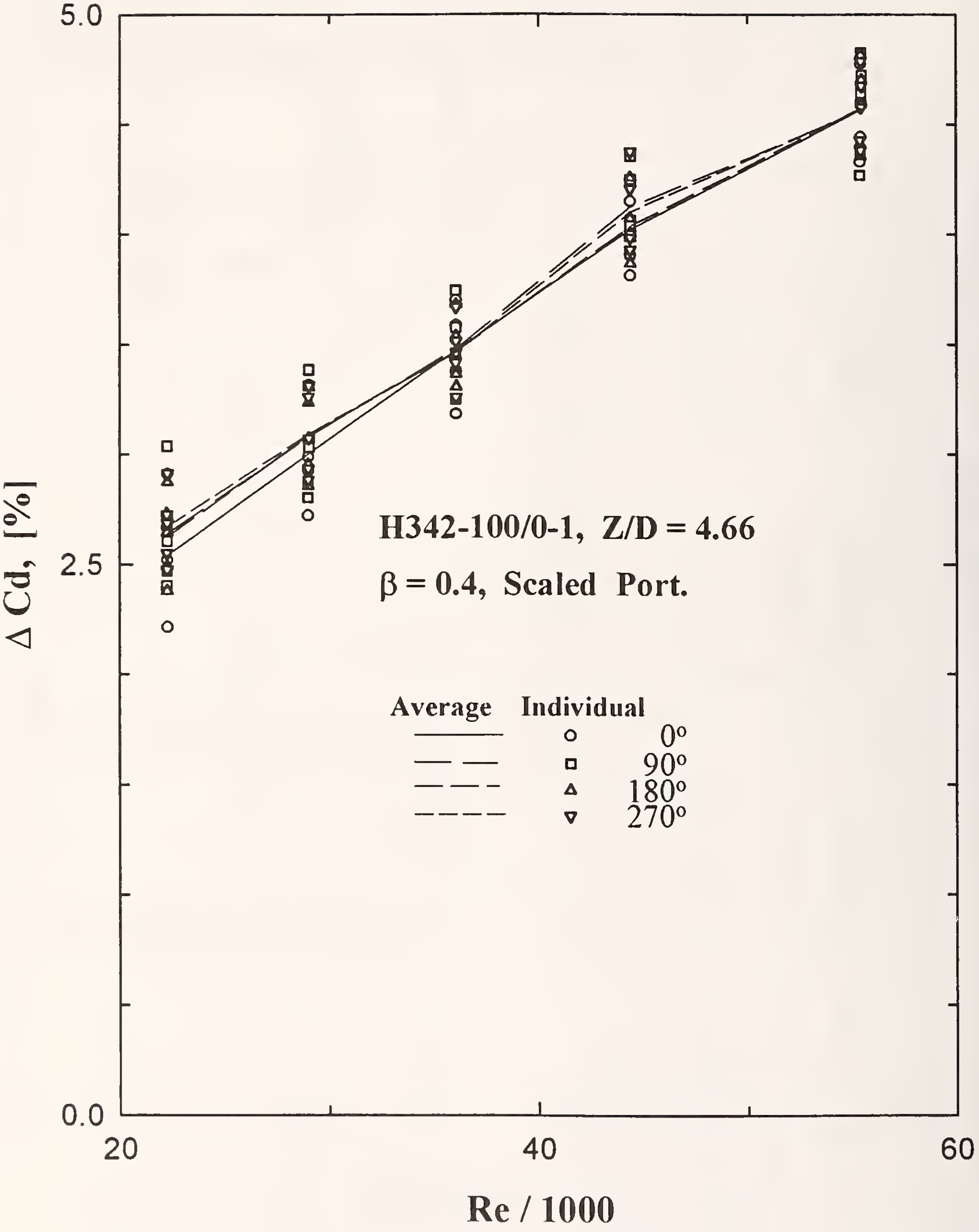


Figure 5. Change in Discharge Coefficients for a Beta =0.4 Orifice Meter at Four Tap Locations Downstream of a Header.

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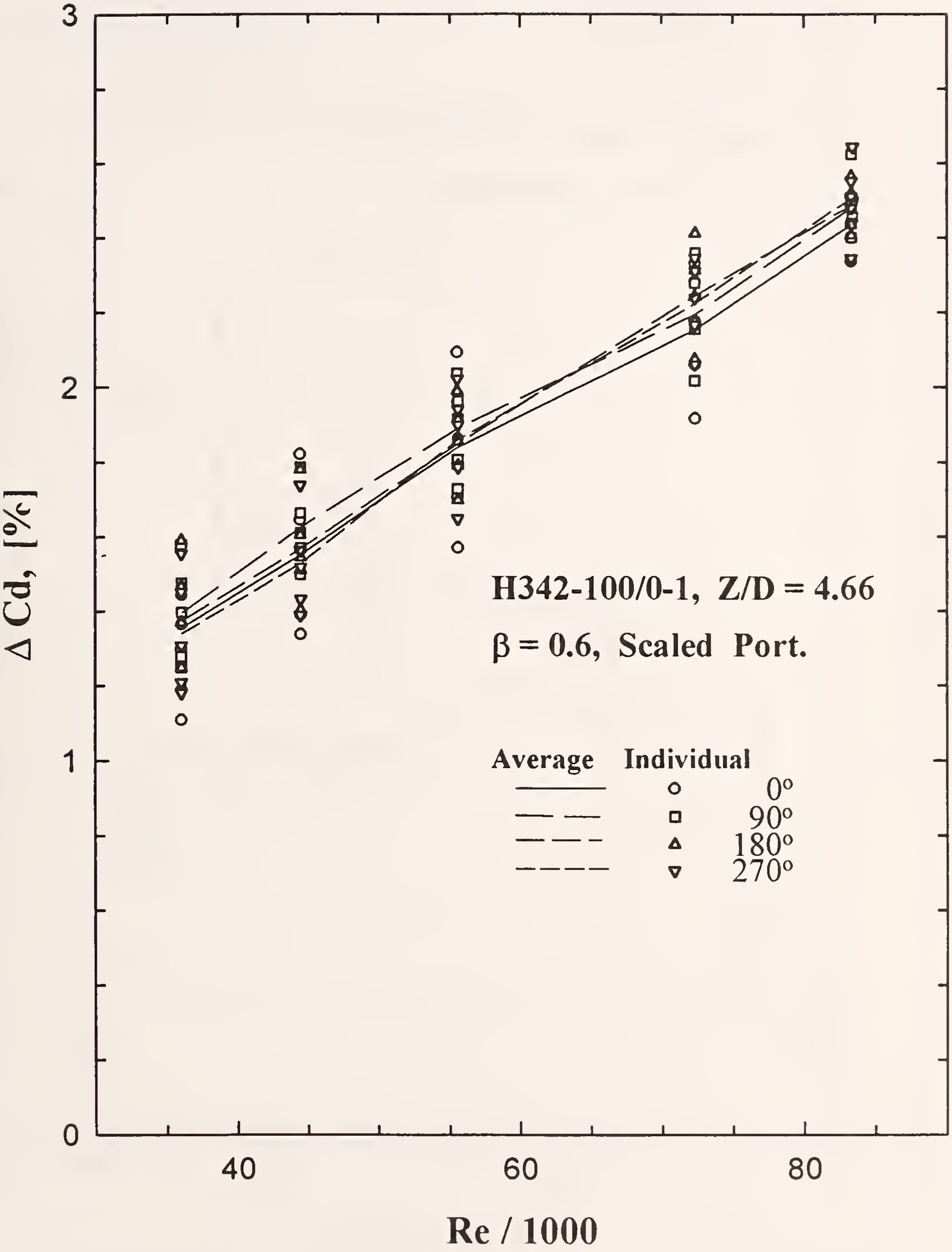


Figure 6. Change in Discharge Coefficients for a Beta =0.6 Orifice Meter Downstream of a Header for four Tap Locations.

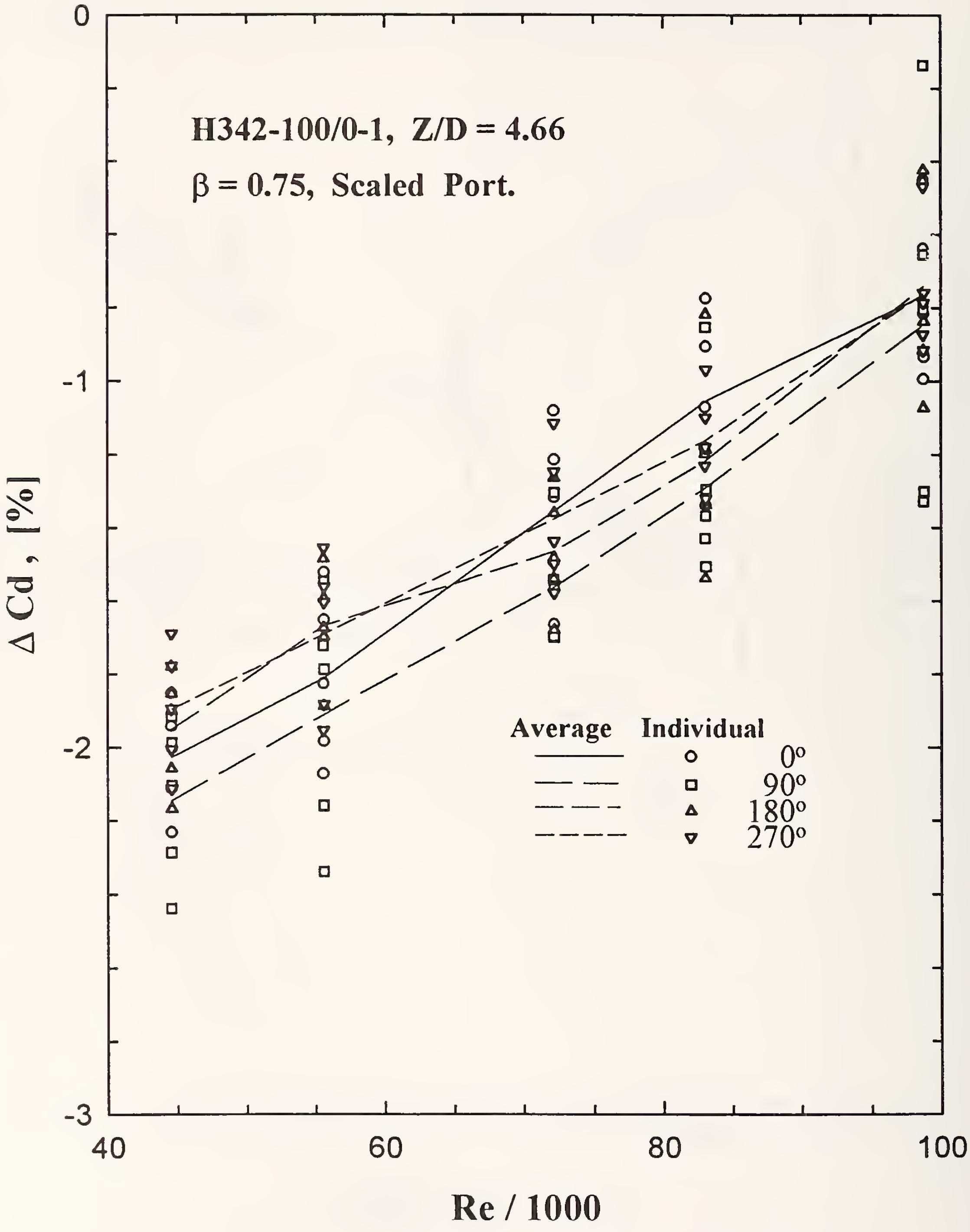


Figure 7. Change in Discharge Coefficients for a Beta =0.75 Orifice Meter Downstream of a Header for four Tap Locations.

C1QH

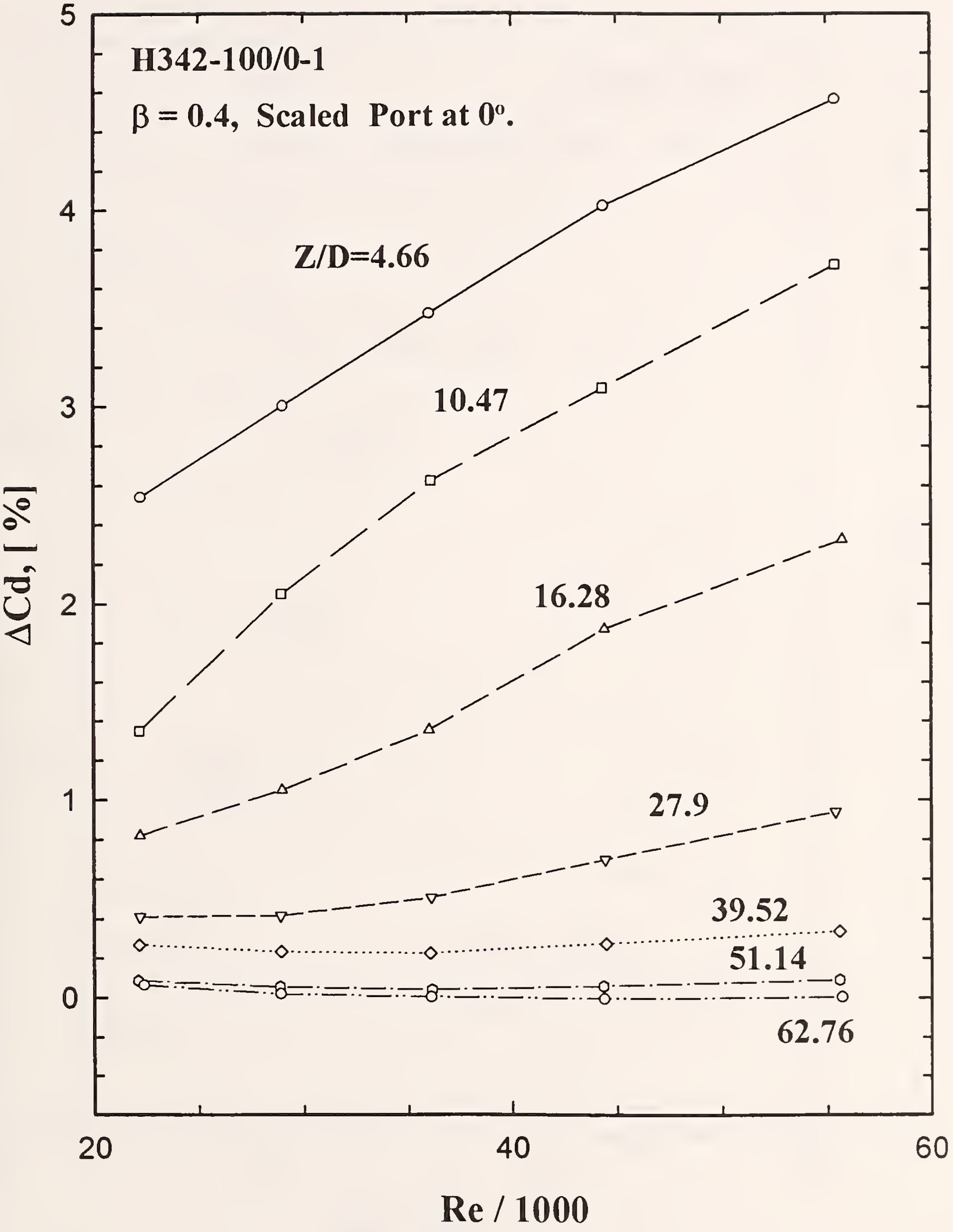


Figure 8. Change in Discharge Coefficients for a Beta =0.4 Orifice Meter at Different Downstream Positions from a Header, H342-100/0-1.

A0QZH

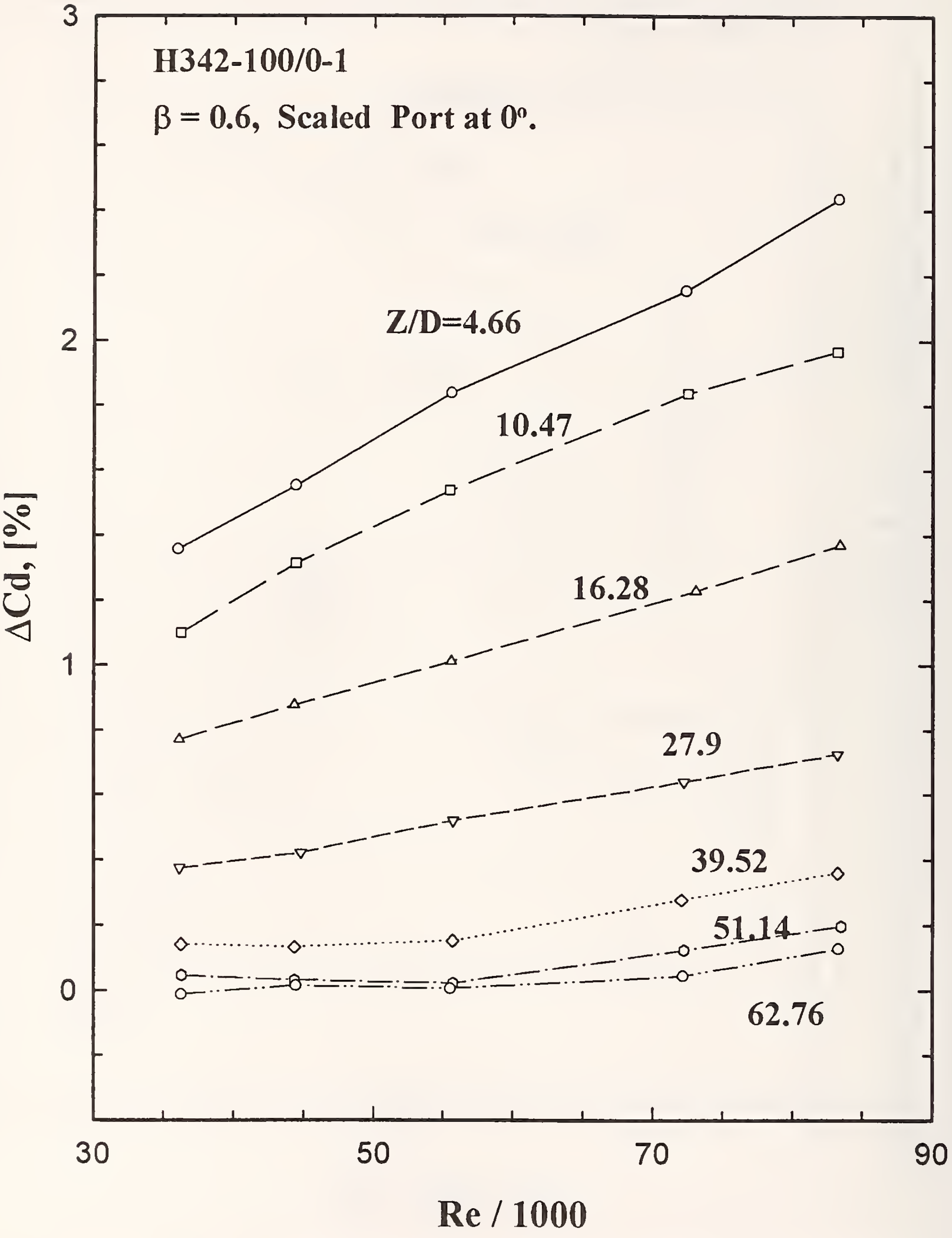


Figure 9. Change in Discharge Coefficients for a Beta =0.6 Orifice Meter at Different Downstream Positions from a Header, H342-100/0-1.

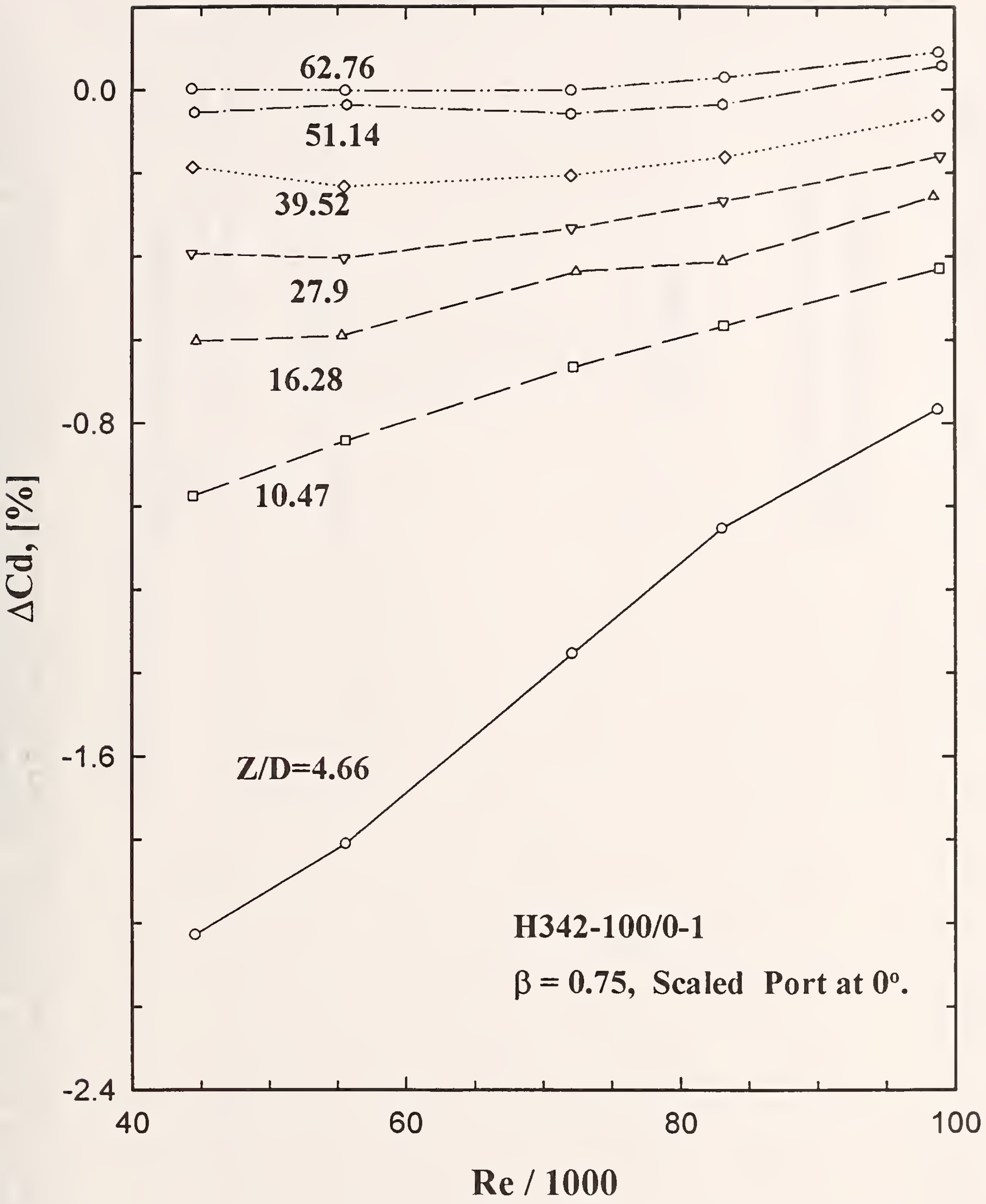


Figure 10. Change in Discharge Coefficients for a Beta =0.75 Orifice Meter at Different Downstream Positiions from a Header, H342-100/0-1.

A0ZH

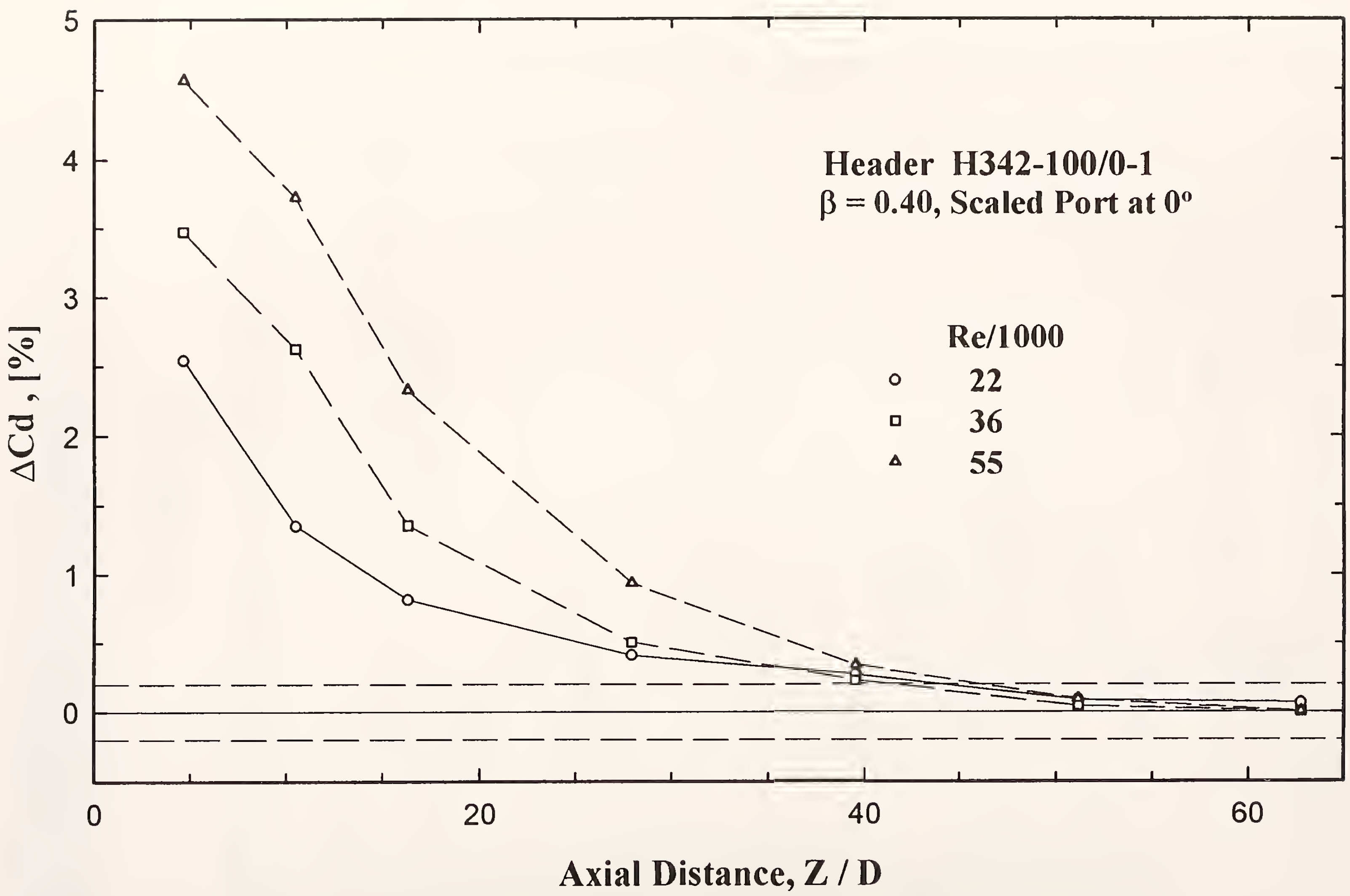


Figure 11. Axial Change in Discharge Coefficients for a Beta =0.4 Orifice Meter Downstream from a Header. Horizontal dash lines Denote the ±0.2% Uncertainty.

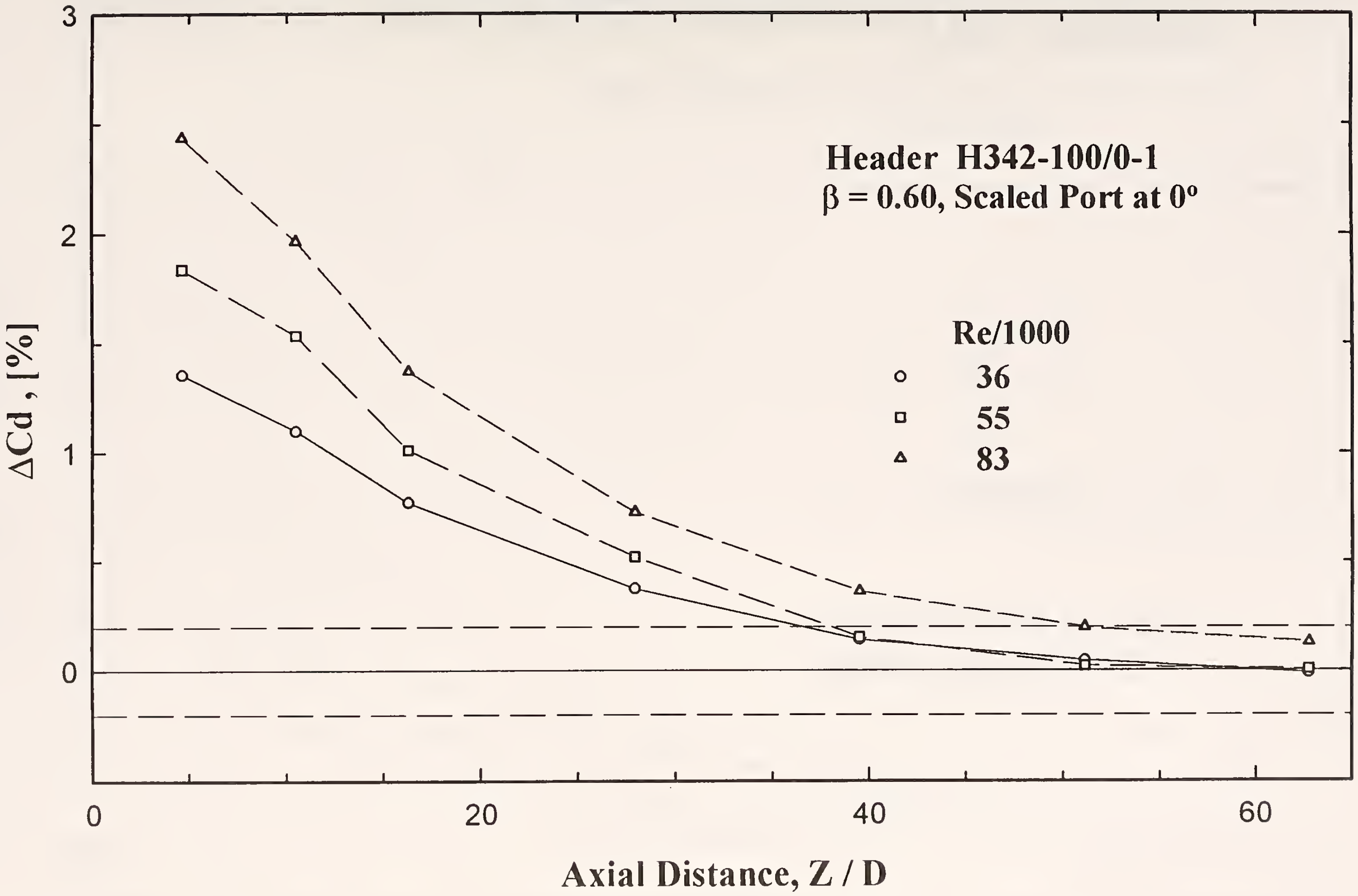


Figure 12. Axial Change in Discharge Coefficients for a Beta =0.6 Orifice Meter Downstream from a Header. Horizontal dash lines Denote the ±0.2% Uncertainty.

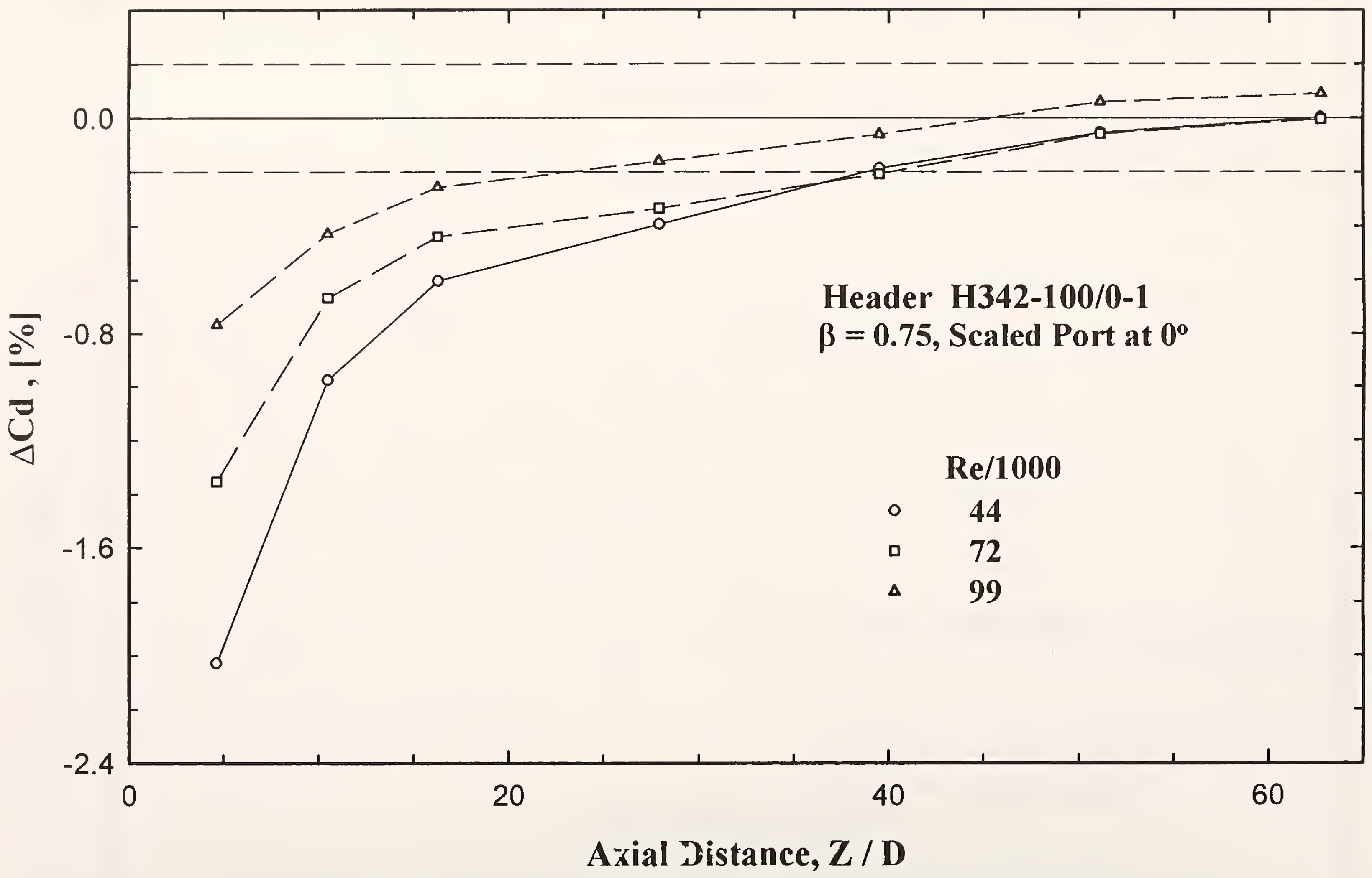


Figure 13. Axial Change in Discharge Coefficients for a Beta =0.75 Orifice Meter Downstream from a Header. Horizontal dash lines Denote the ±0.2% Uncertainty.

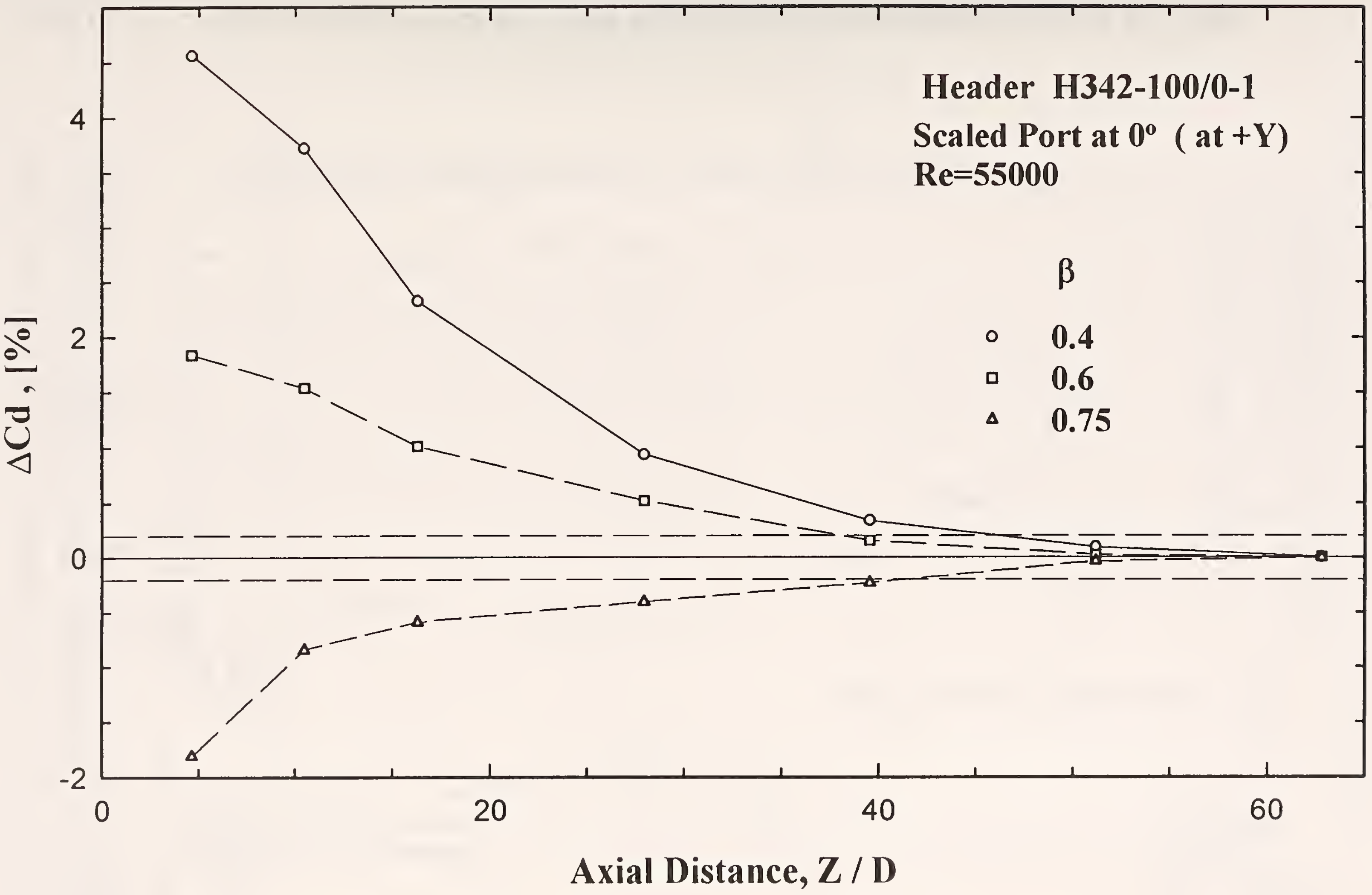
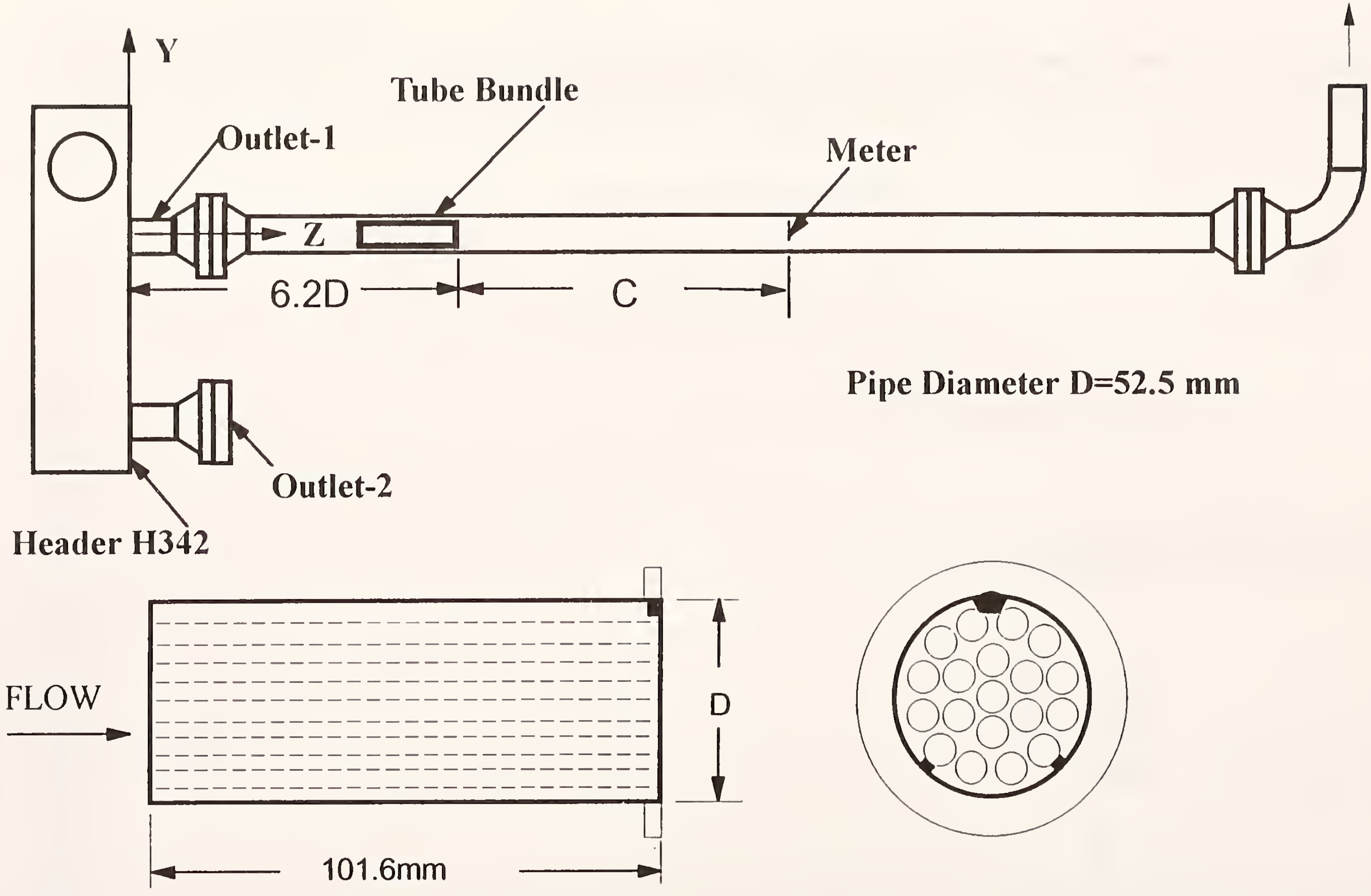


Figure 14. Axial Change in Discharge Coefficients for a Range of Orifice Meters Downstream from a Header for Re=55000. Horizontal Dash Lines Denote the ±0.2% Uncertainty.



19-Tube Tube Bundle(9.5mm ID, 0.4mm wall thickness)

Figure 15. Sketches of a Header with Tube Bundle Installation and a 19 Tube, Concentric Tube Bundle Arrangement.

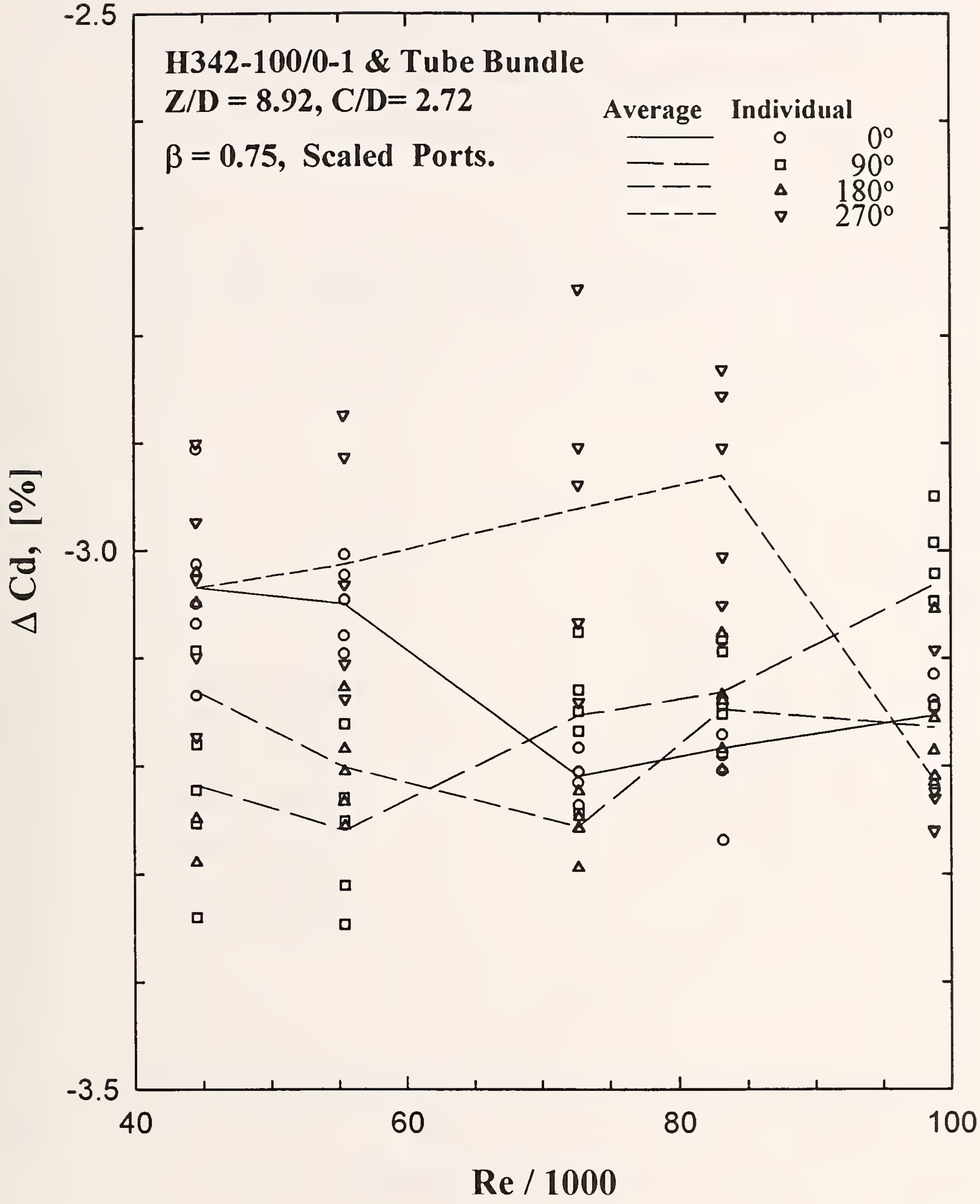


Figure 16. Change in Discharge Coefficients for a Beta =0.75 Orifice Meter Downstream of a Header and a 19-Tube Tube Bundle for Four Tap Locations.

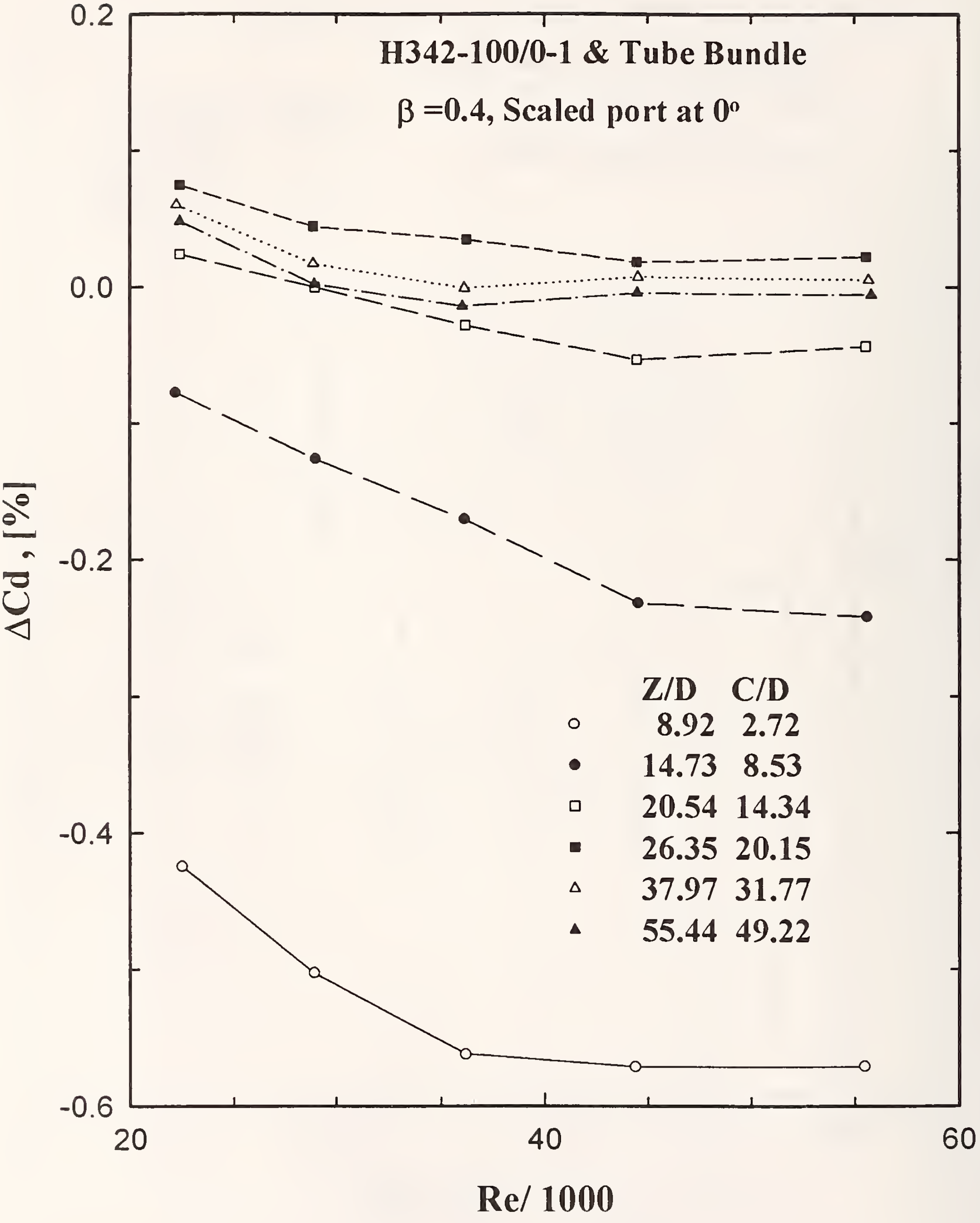


Figure 17. Change in Discharge Coefficients for a Beta =0.4 Orifice Meter at Different Downstream Positions from a Header, H342-100/0-1 and a 19-Tube Tube Bundle.

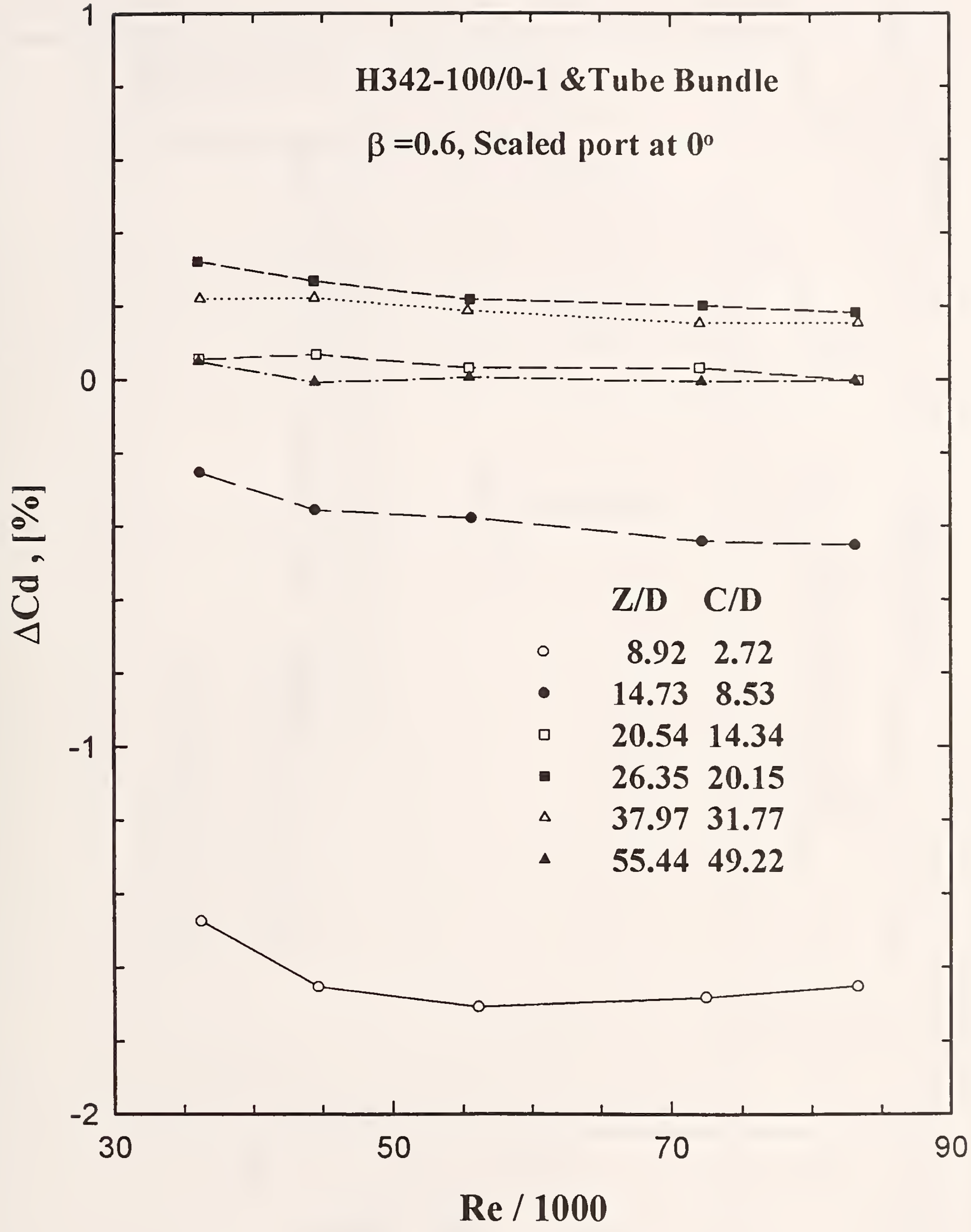


Figure 18. Change in Discharge Coefficients for a Beta =0.6 Orifice Meter at Different Downstream Positions from a Header, H342-100/0-1 and a 19-Tube Tube Bundle.

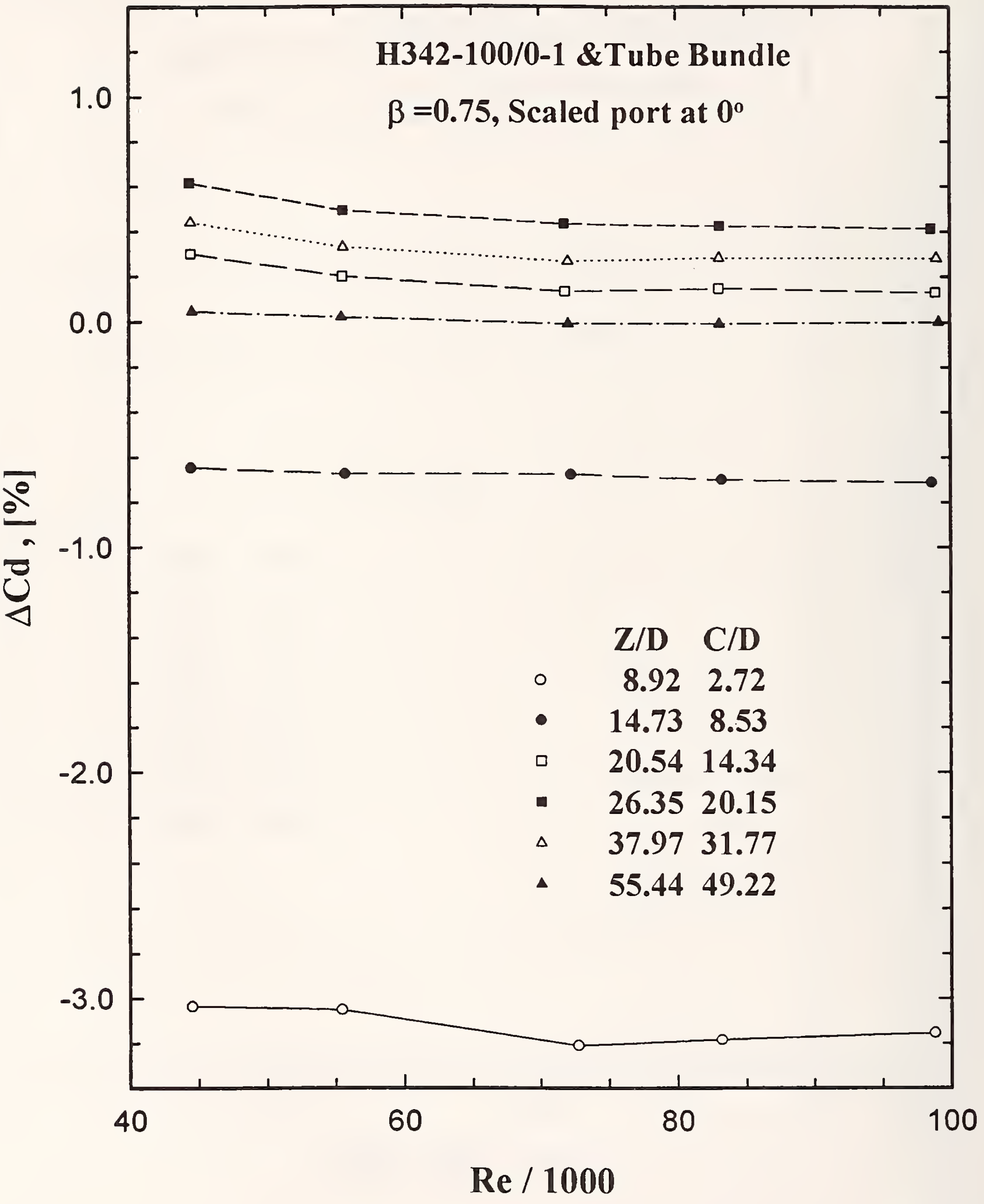


Figure 19. Change in Discharge Coefficients for a Beta =0.75 Orifice Meter at Different Downstream Positions from a Header, H342-100/0-1 and a 19-Tube Tube Bundle.

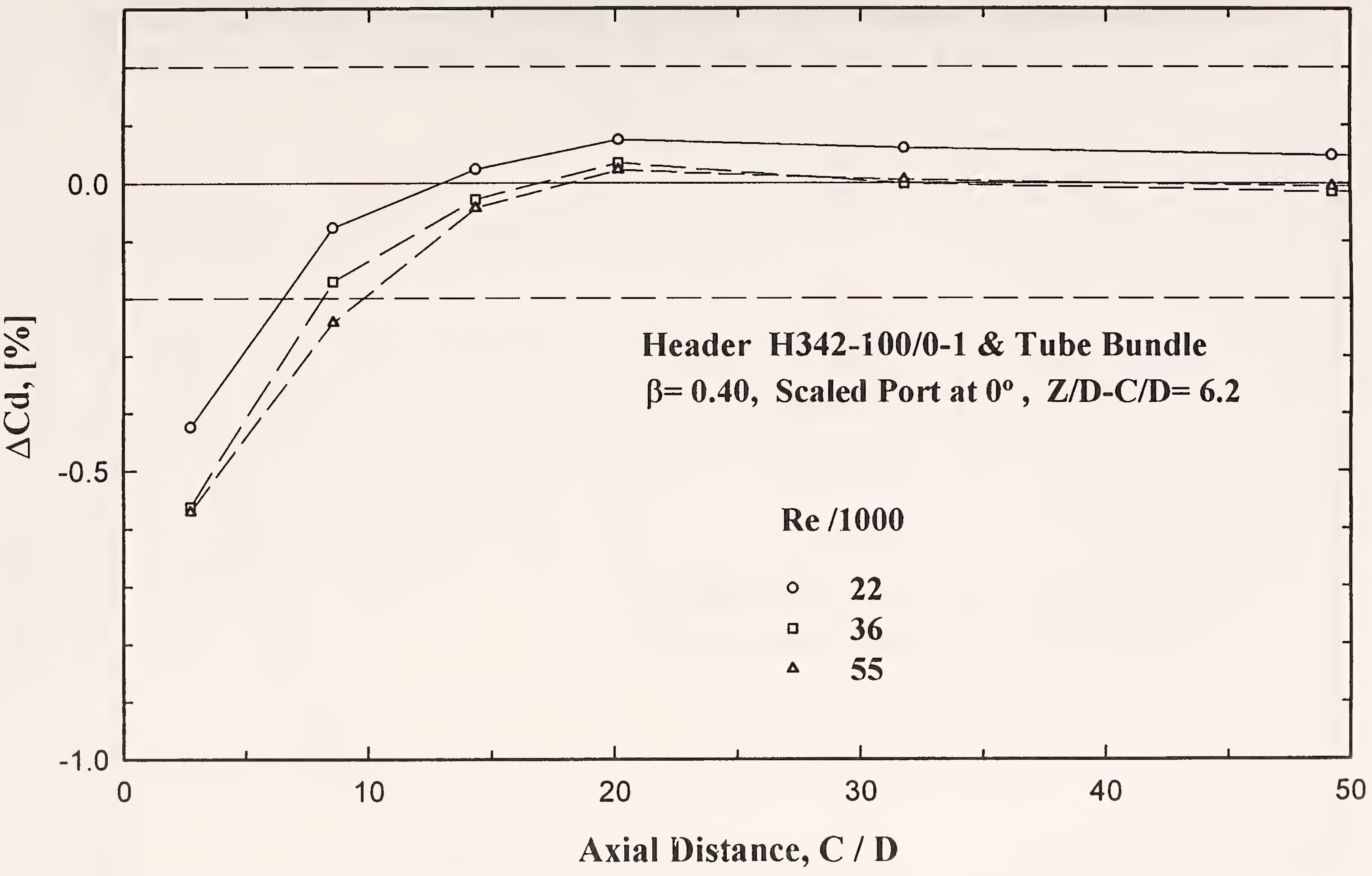


Figure 20. Axial Change in Discharge Coefficients for a Beta =0.4 Orifice Meter Downstream from a Header and a 19-Tube Tube Bundle. Horizontal dash lines Denote the ±0.2% Uncertainty.

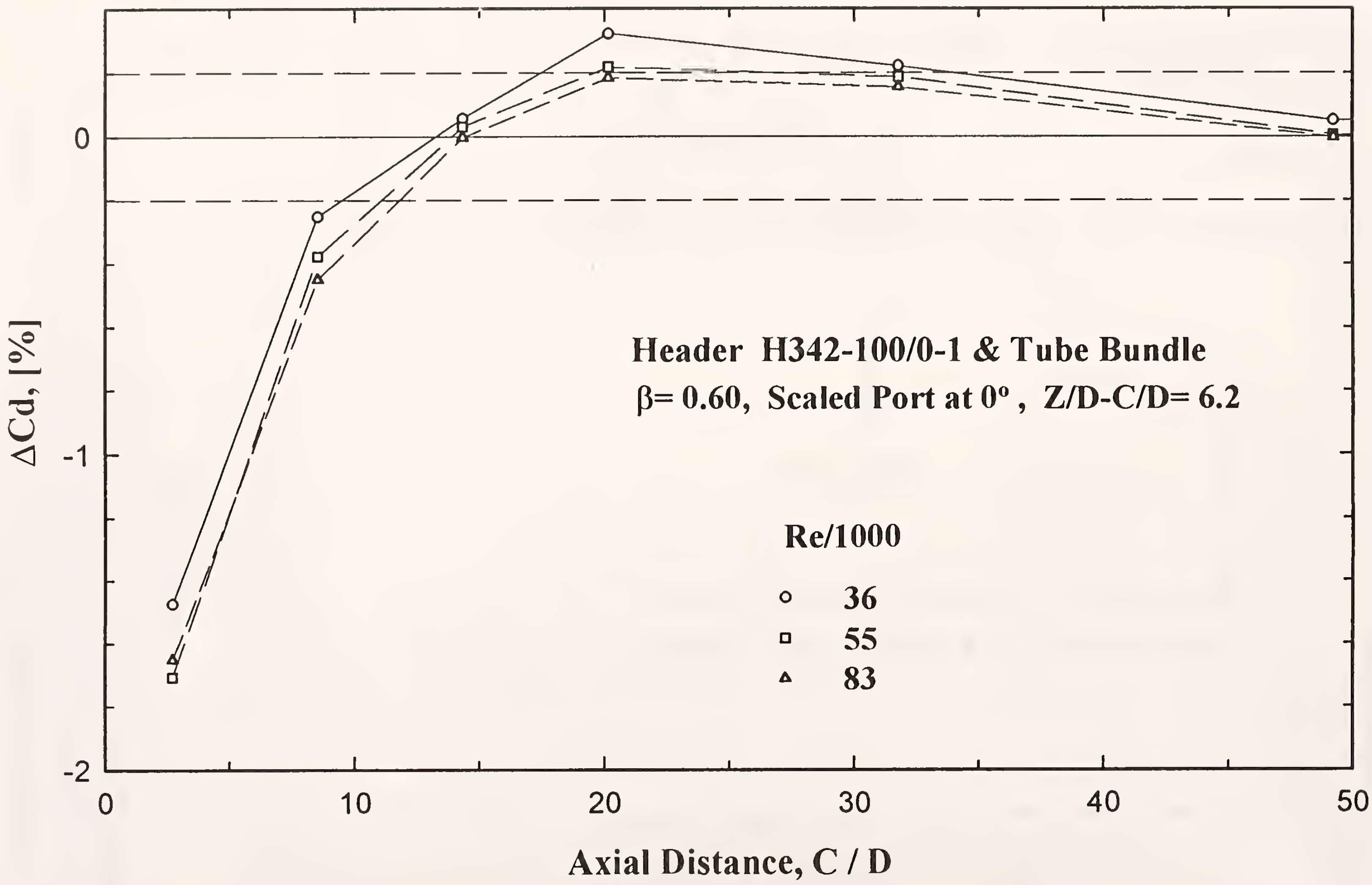


Figure 21. Axial Change in Discharge Coefficients for a Beta =0.6 Orifice Meter Downstream from a Header and a 19-Tube Tube Bundle. Horizontal dash lines Denote the ±0.2% Uncertainty.

C0ZHF

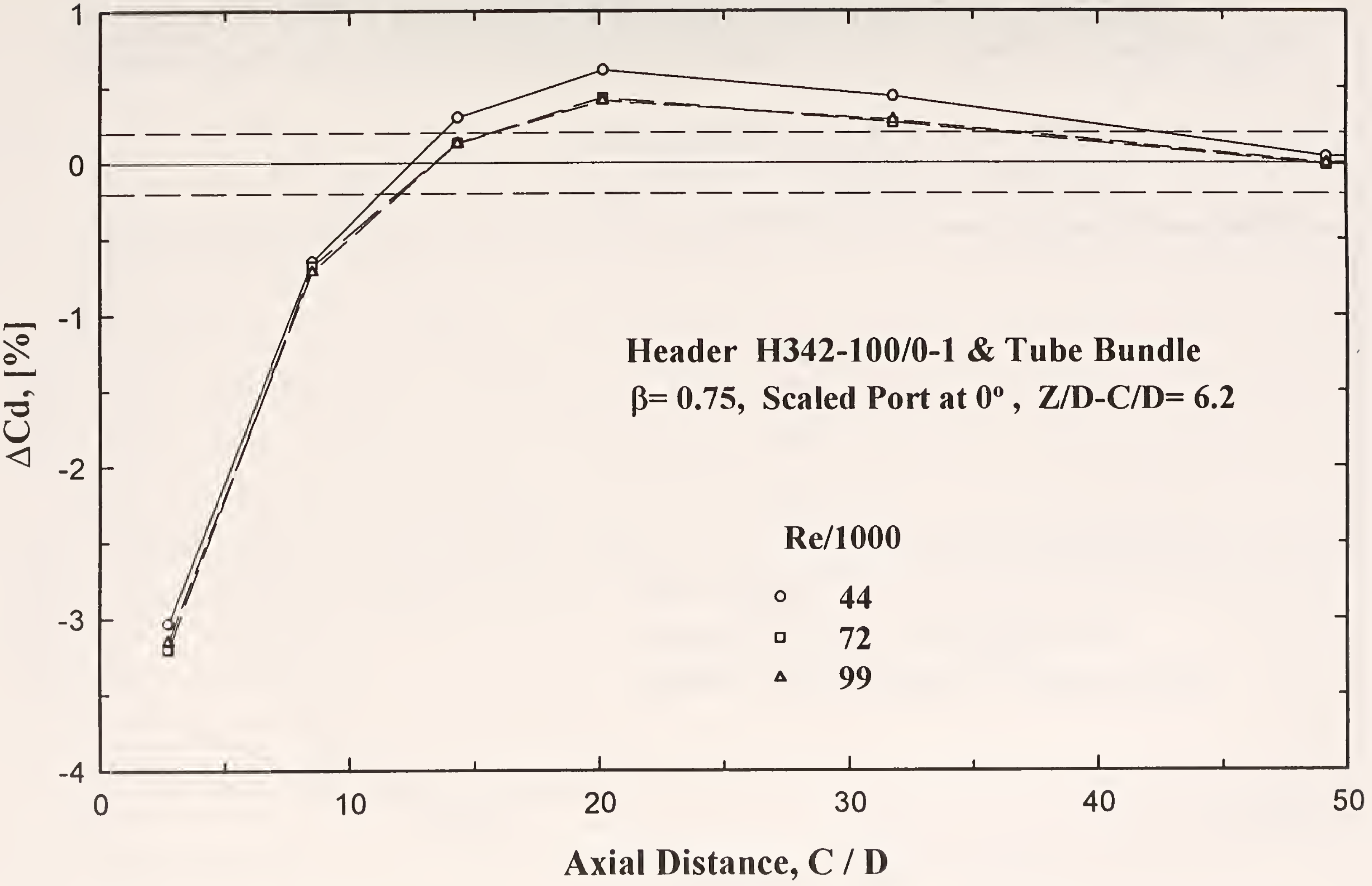


Figure 22. Axial Change in Discharge Coefficients for a Beta =0.75 Orifice Meter Downstream from a Header and a 19-Tube Tube Bundle. Horizontal dash lines Denote the ±0.2% Uncertainty.

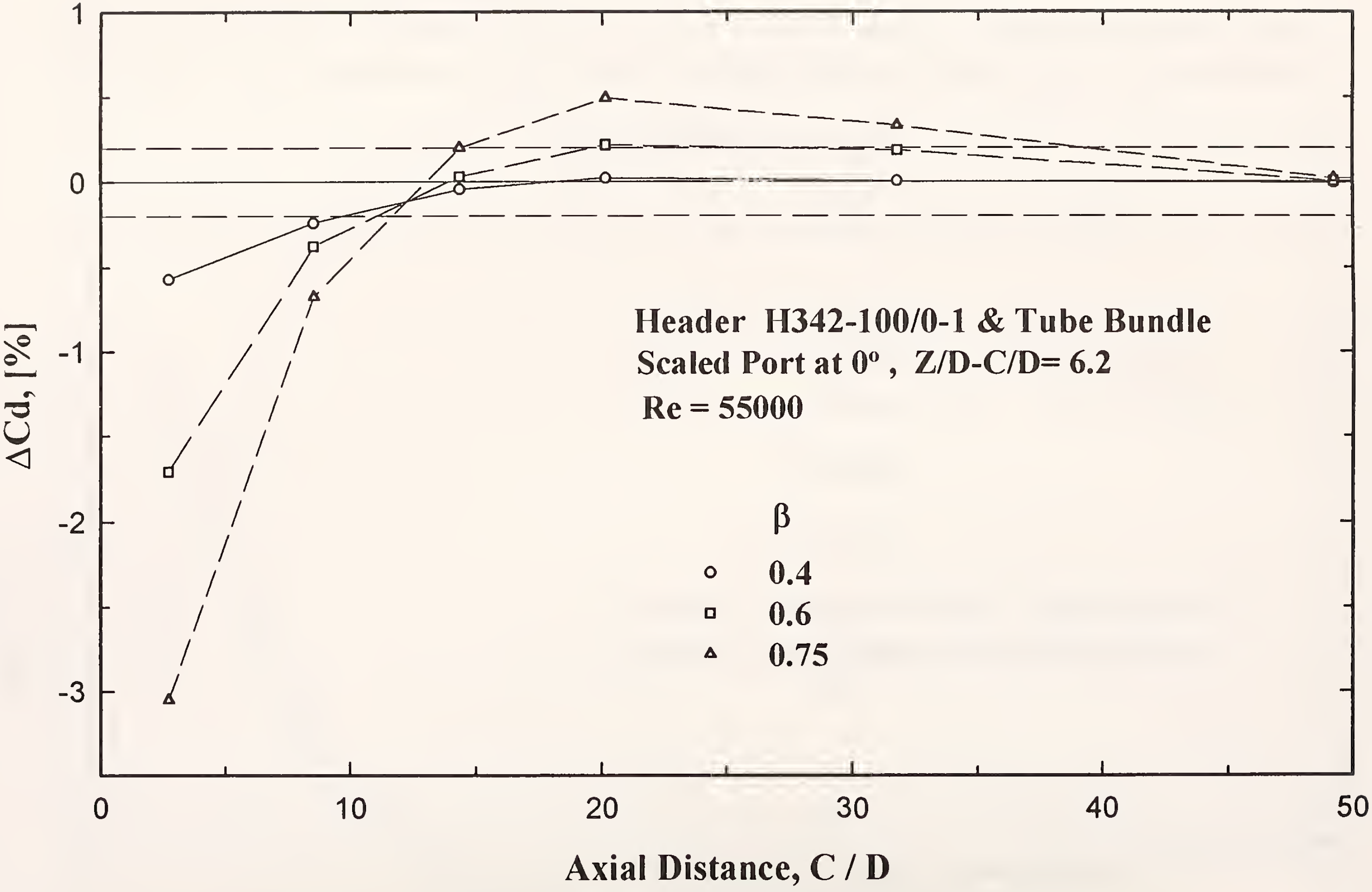


Figure 23. Axial Change in Discharge Coefficients for a Range of Orifice Meters Downstream from a Header and a 19-Tube Tube Bundle for Re=55000. Horizontal dash lines Denote the +0.2% Uncertainty.

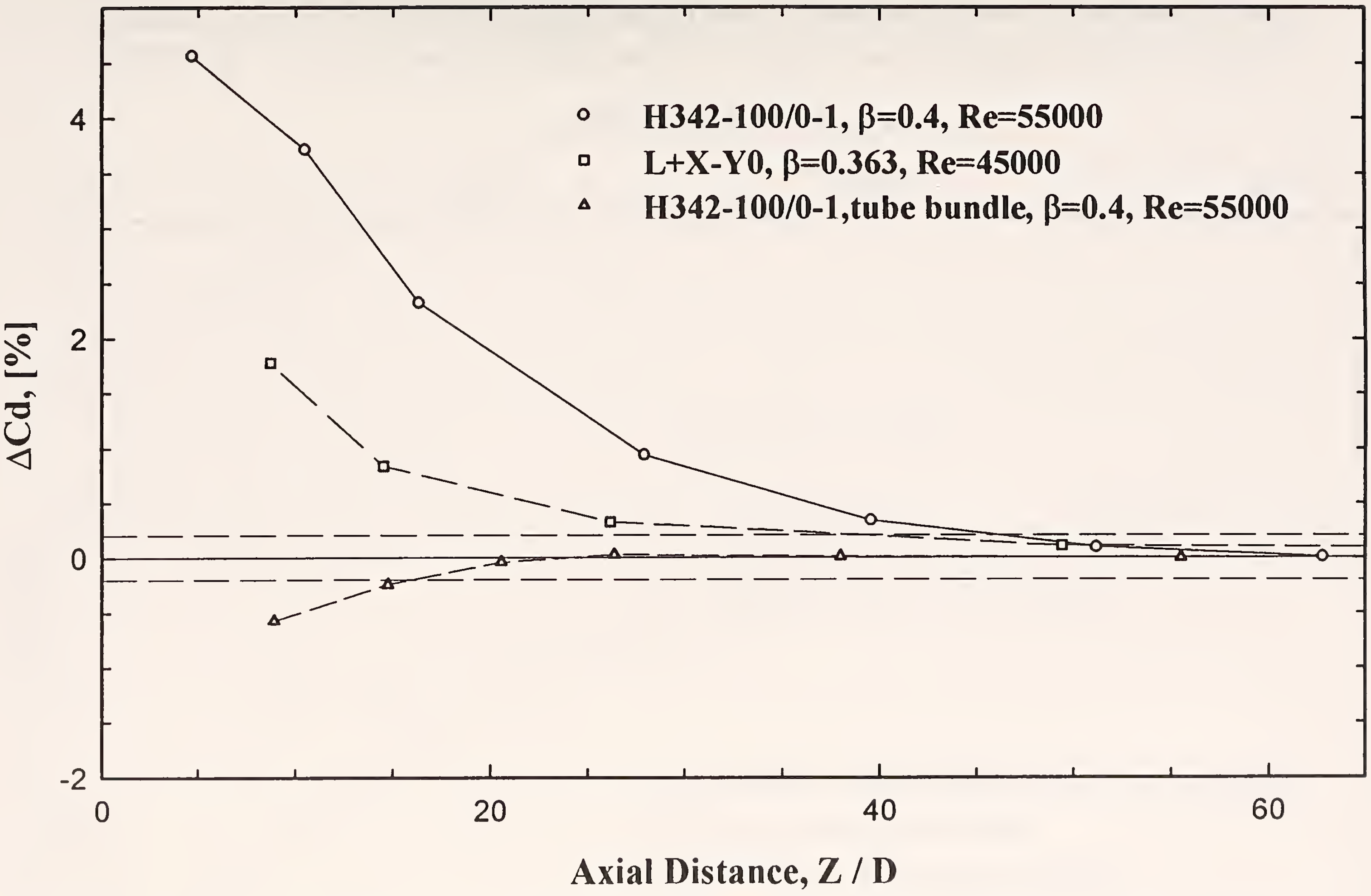


Figure 24. Axial Change in Discharge Coefficients for Small Beta Orifice Meters Downstream from Different Piping Configurations . Horizontal dash lines Denote the ±0.2% Uncertainty.

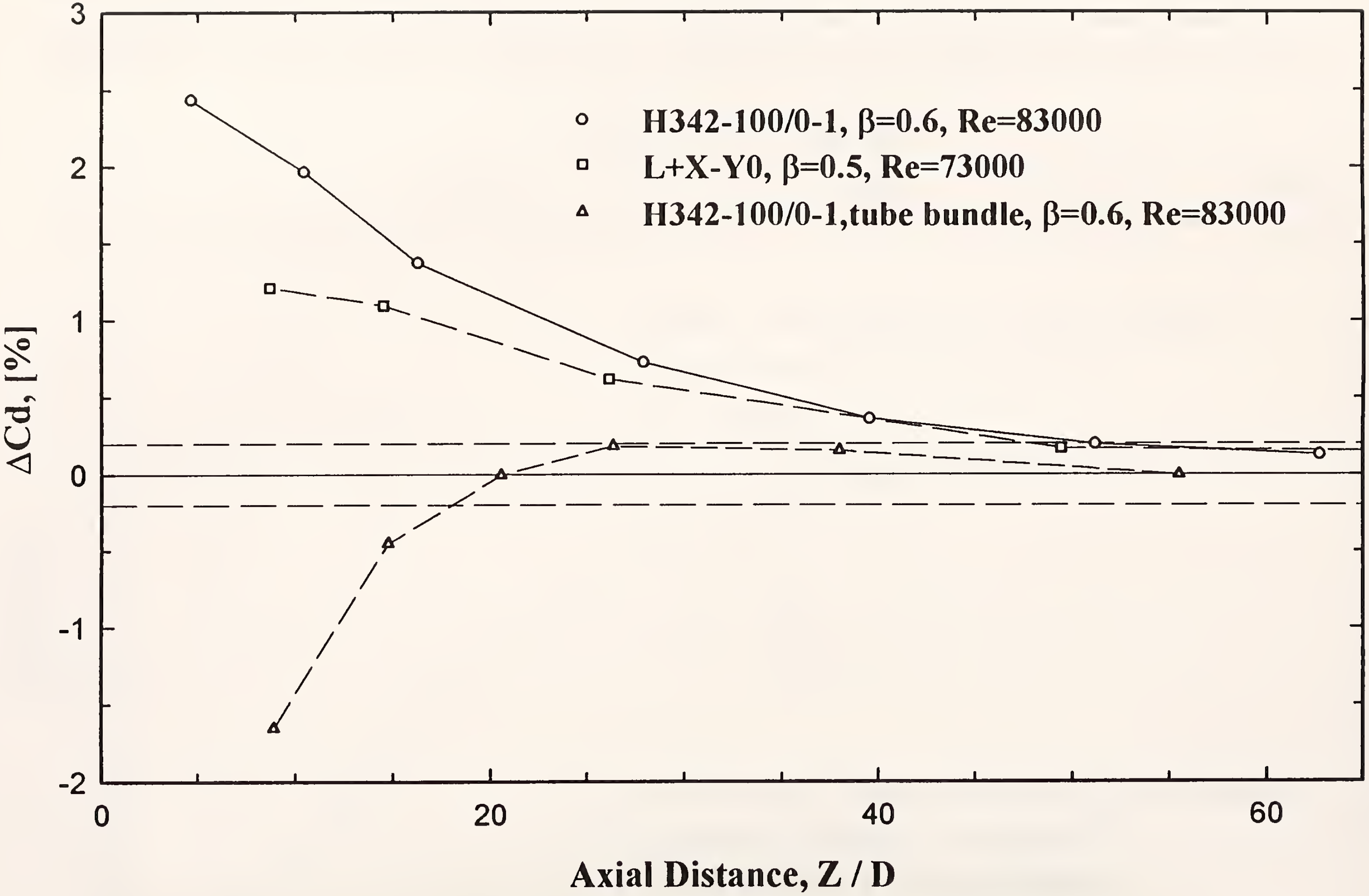


Figure 25. Axial Change in Discharge Coefficients for Medium Beta Orifice Meters Downstream from Different Piping Configurations. Horizontal dash lines Denote the ±0.2% Uncertainty.

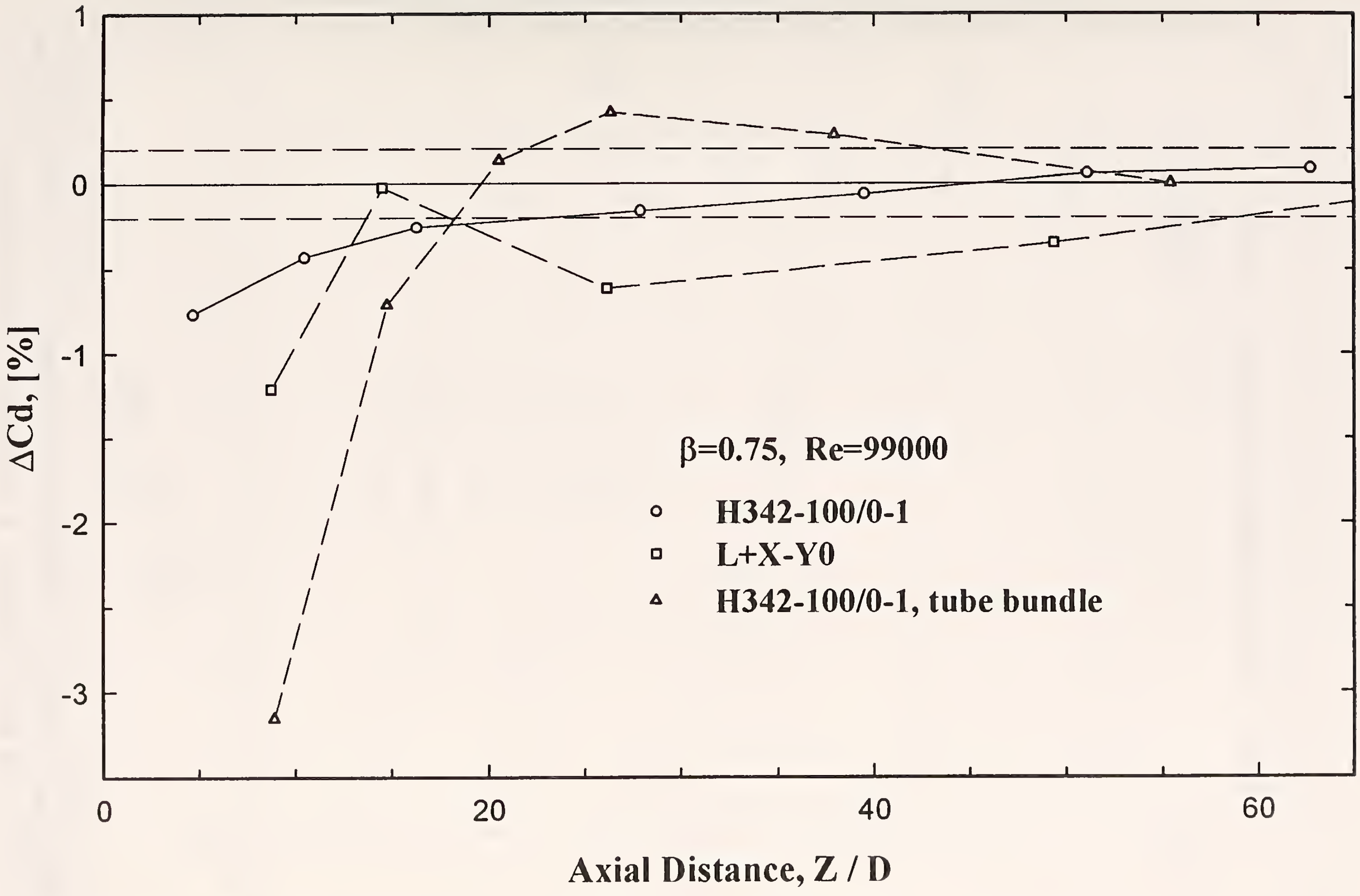


Figure 26. Axial Change in Discharge Coefficients for a Beta=0.75 Orifice Meter Downstream from Different Piping Configurations. Horizontal dash lines Denote the ±0.2% Uncertainty.

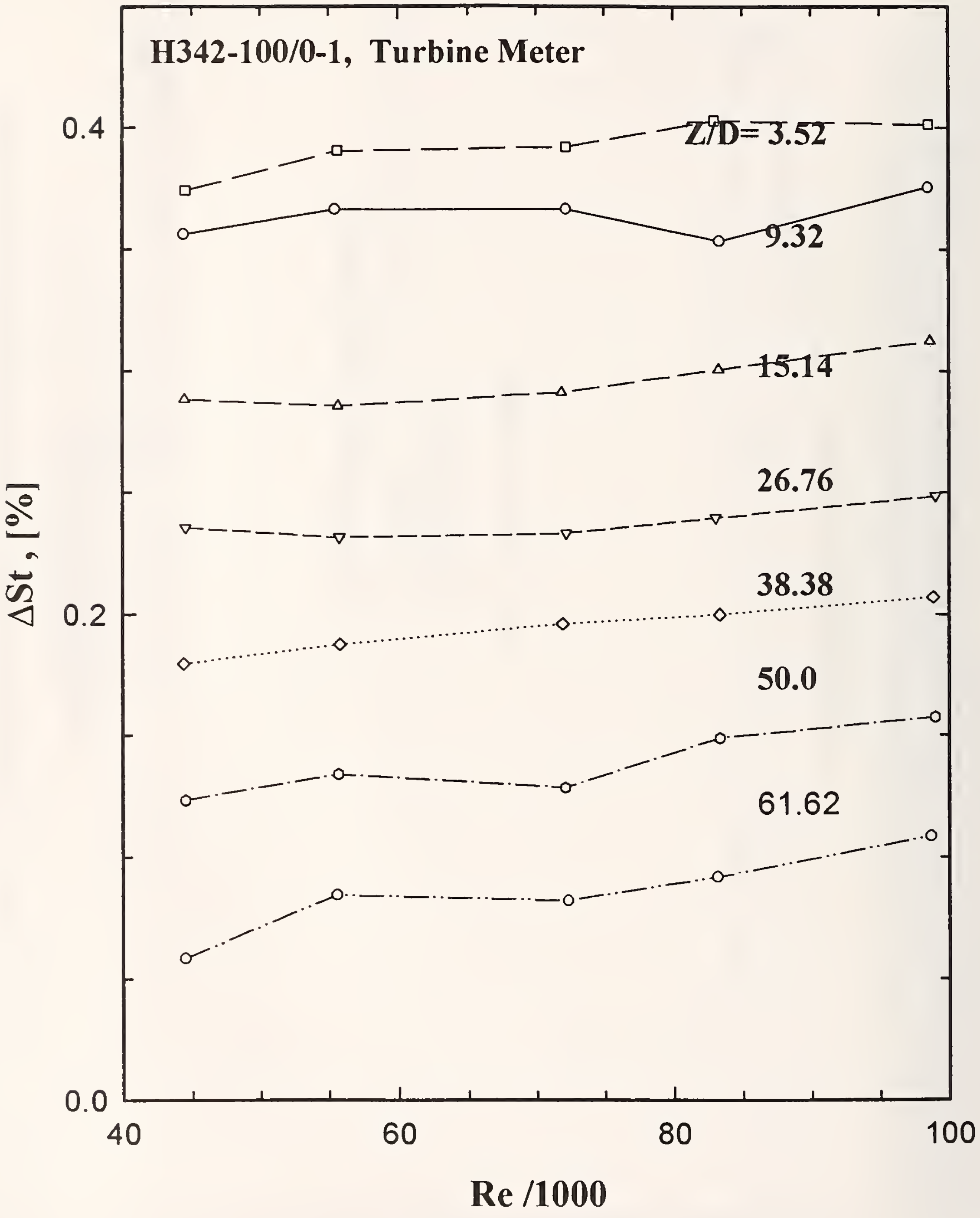


Figure 27. Change in Meter Constant for a Turbine Meter at Different Downstream Positions from a Header.

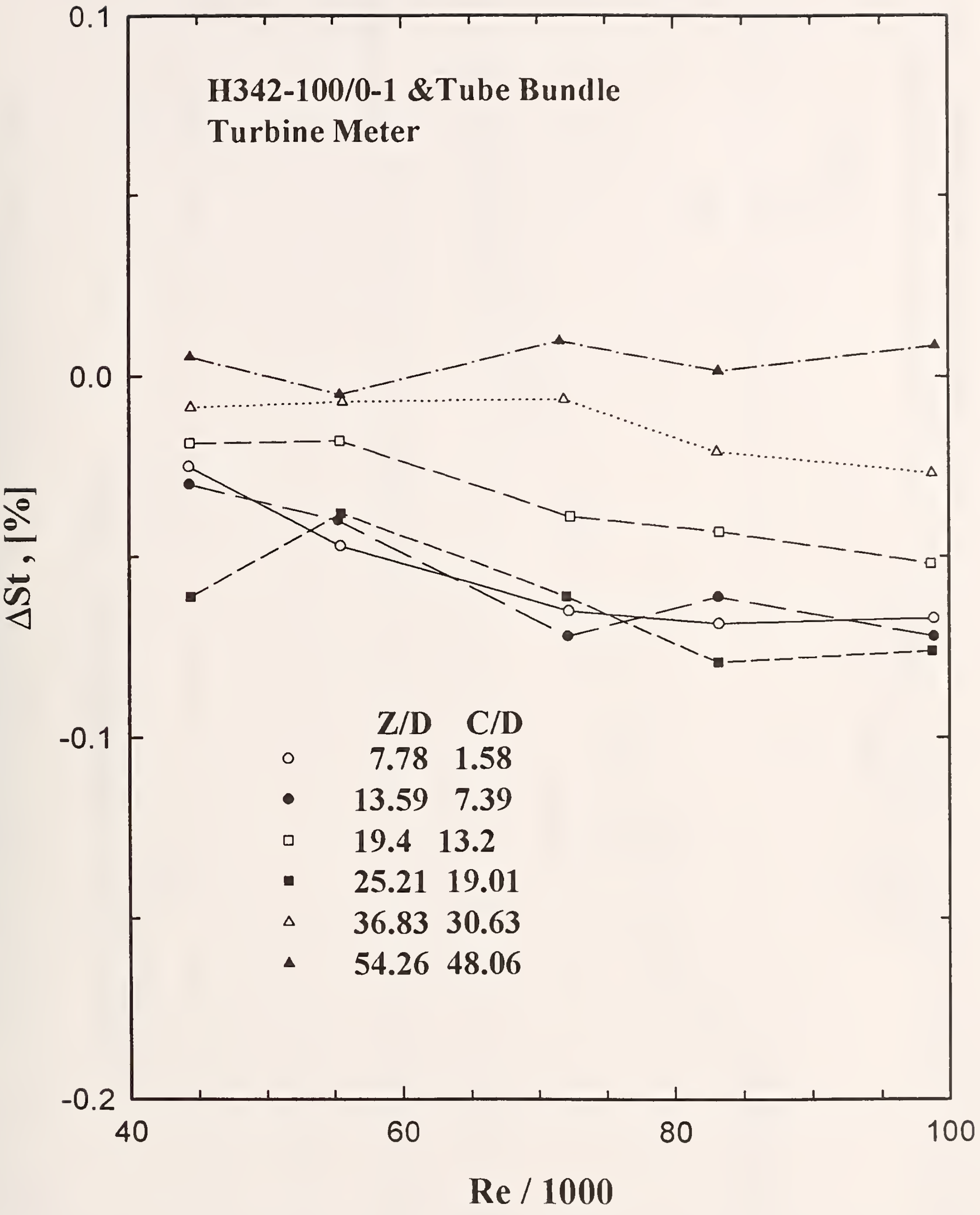


Figure 28. Change in Meter Constant for a Turbine Meter at Different Downstream Positions from a Header and a 19-Tube Tube Bundle.

TQZHF

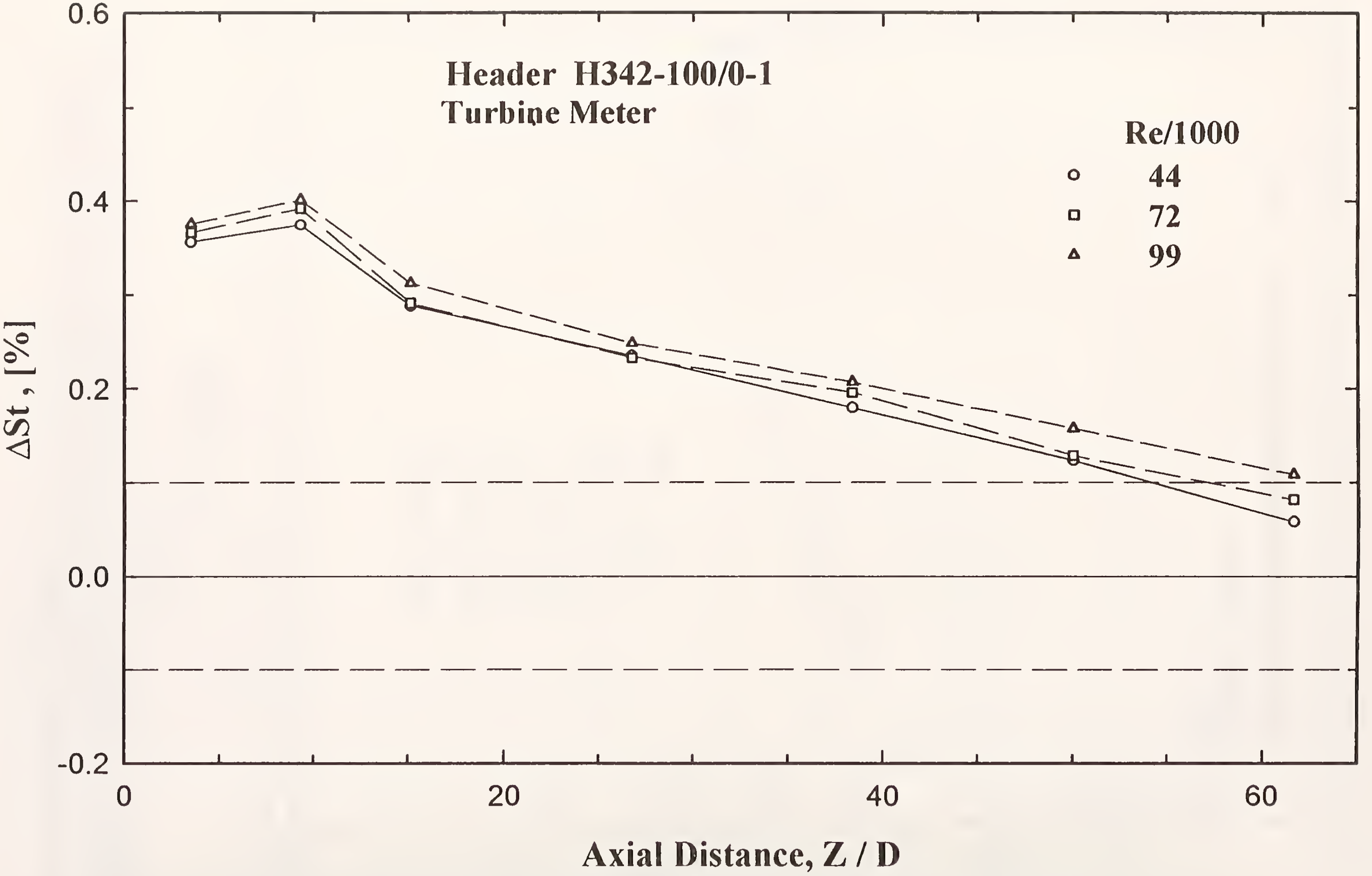


Figure 29. Axial Change in Meter Constant for a Turbine Meter Downstream from a Header. Horizontal dash lines Denote the ±0.1% Uncertainty.

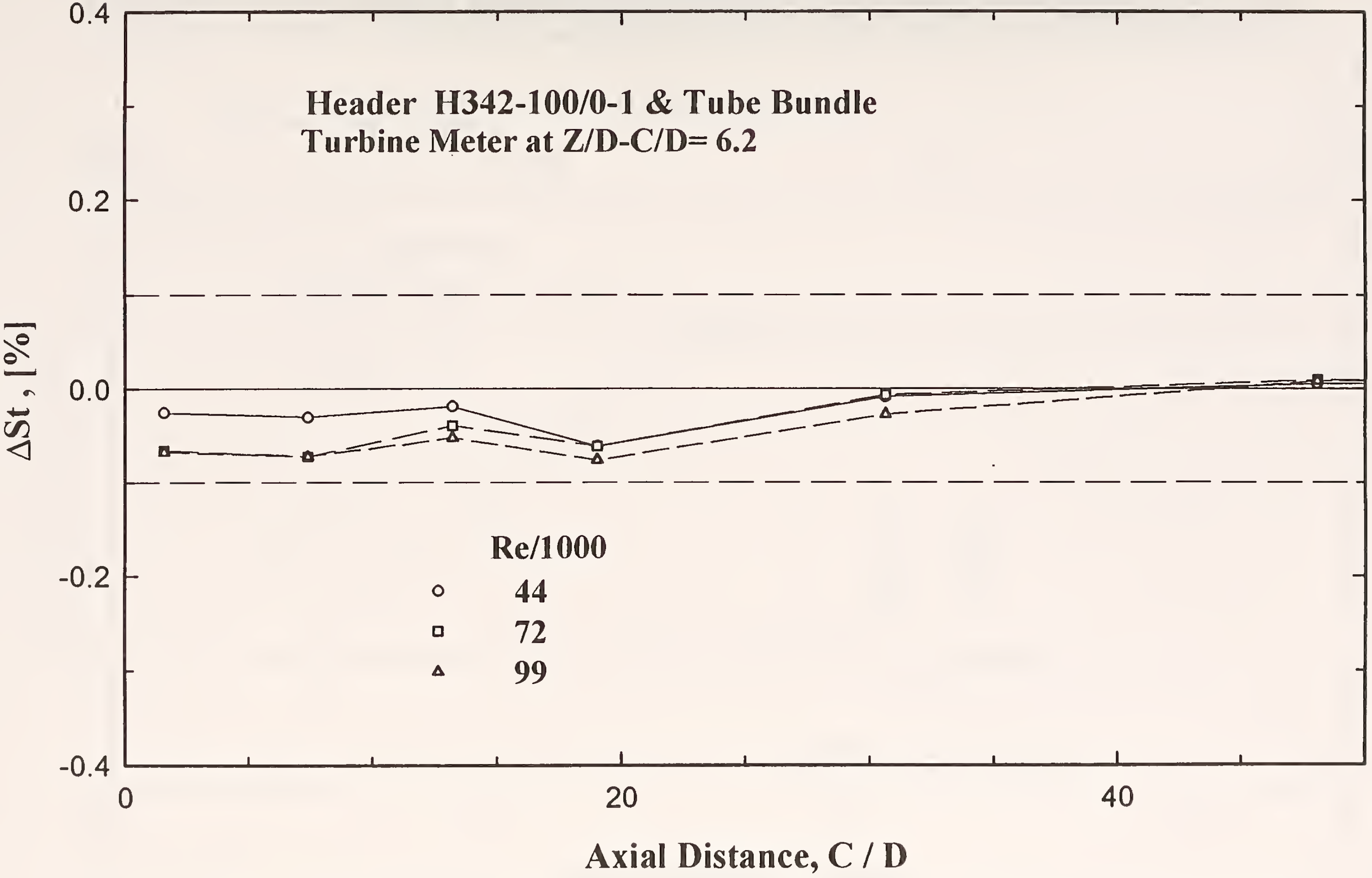


Figure 30. Axial Change in Meter Constant for a Turbine Meter Downstream from a Header and a 19-Tube Tube Bundle. Horizontal dash lines Denote the ±0.1% Uncertainty.

CdS1

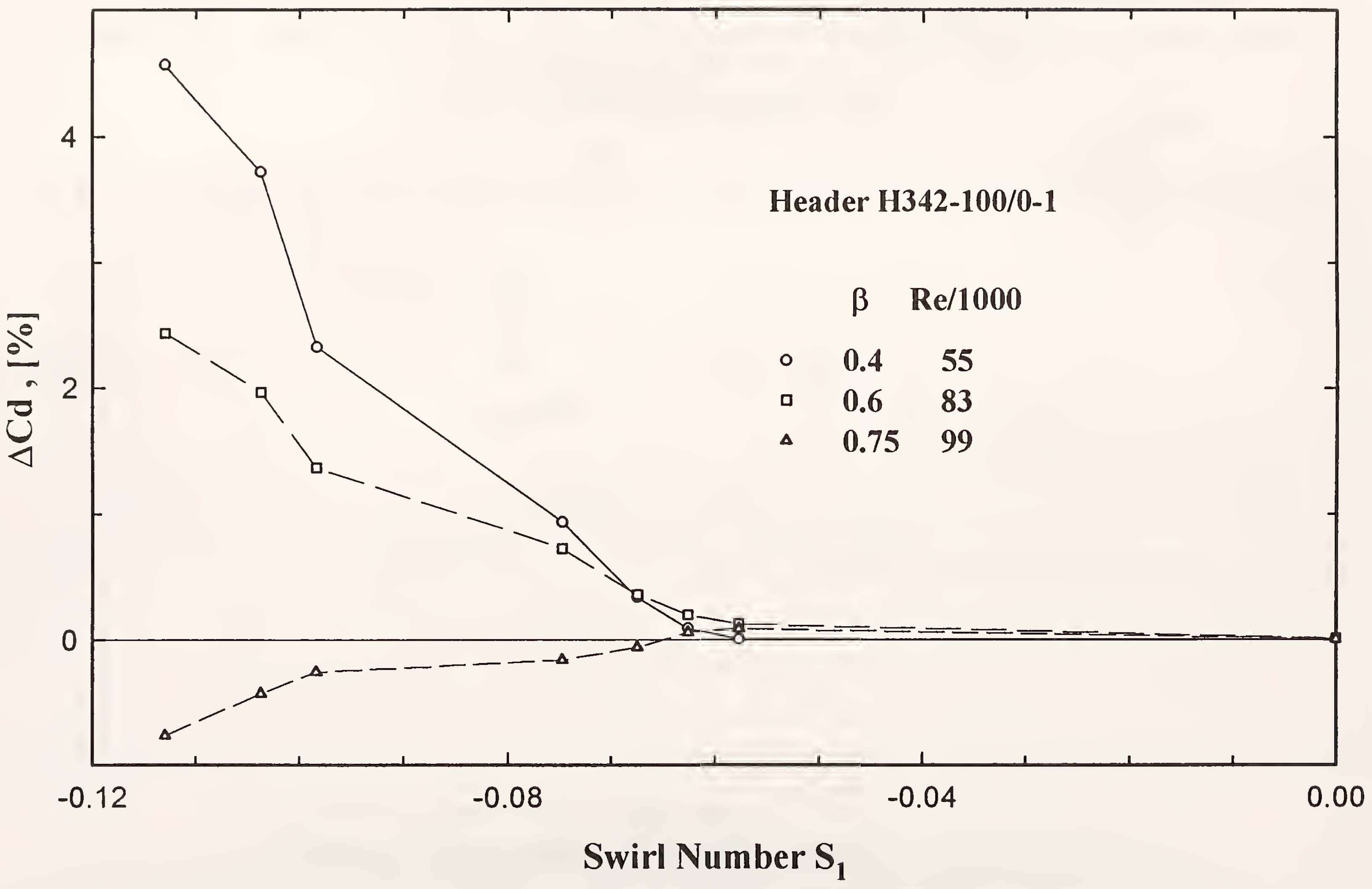


Figure 31. Relationship Between the Change in Discharge Coefficients and the Swirl Number $S_1$ for a Range of Beta Ratios.

CdSa

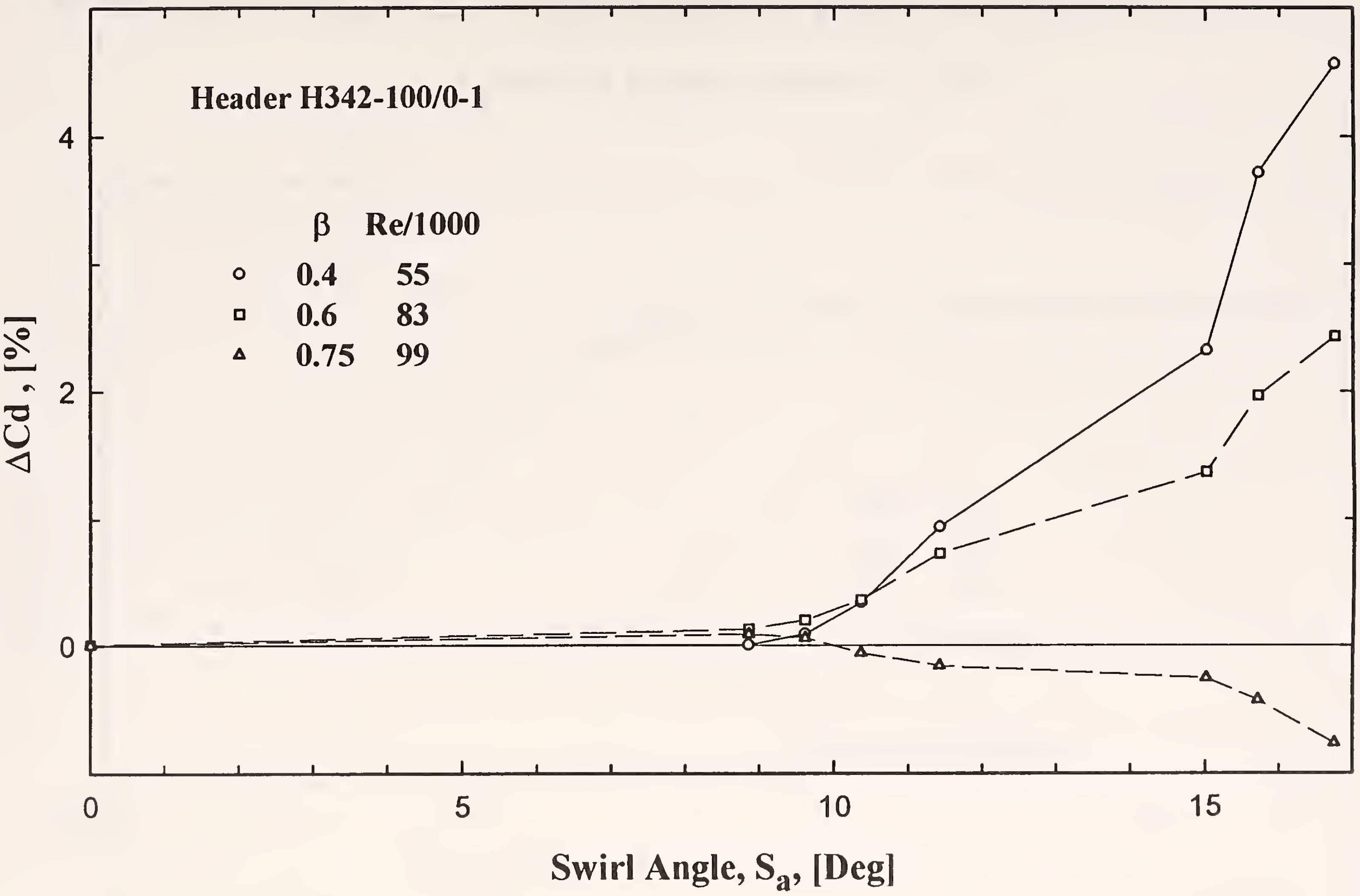


Figure 32. Relationship Between the Change in Discharge Coefficients and the Swirl Angle $S_a$ for a Range of Beta Ratios.

CdP6

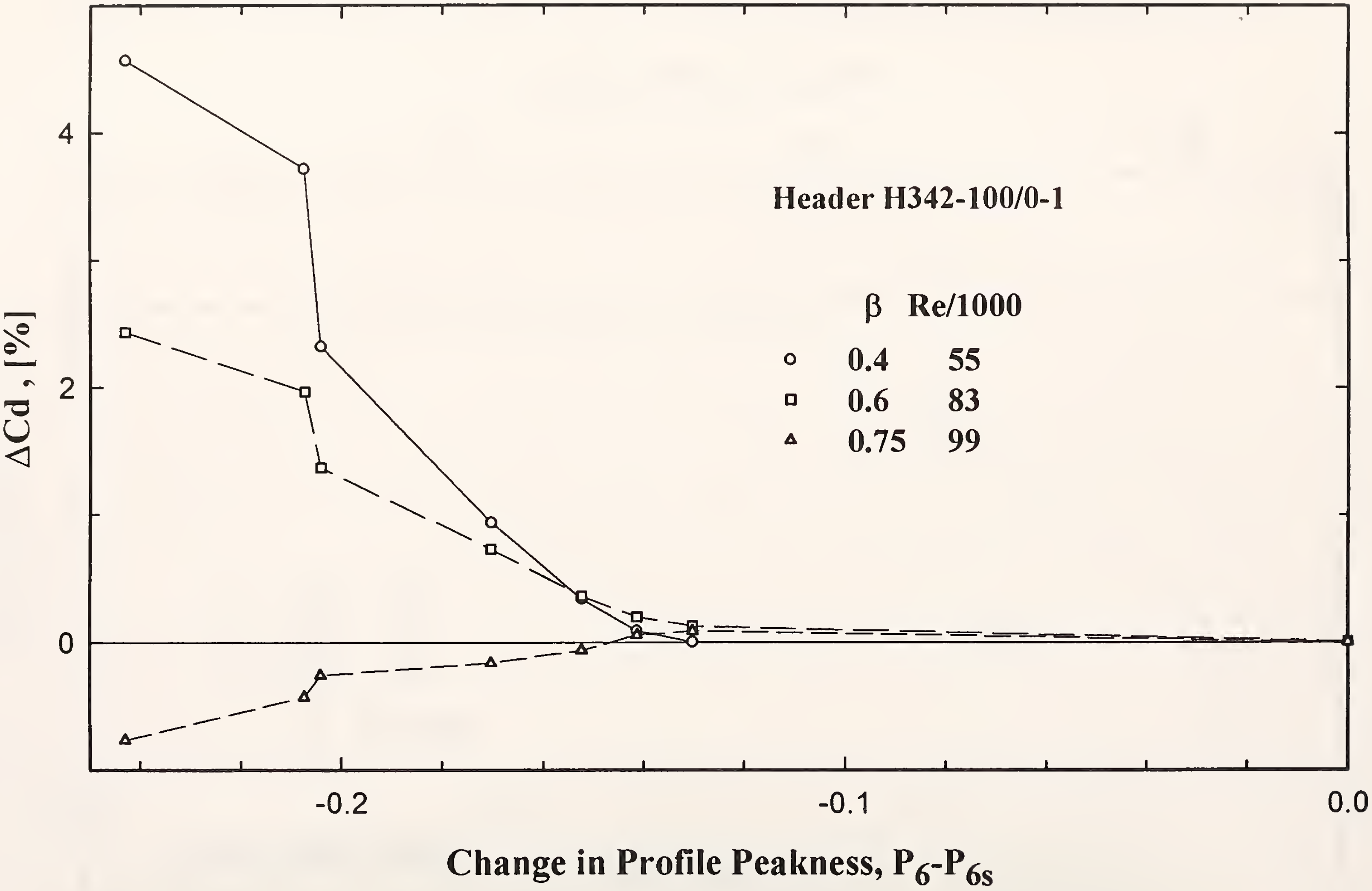


Figure 33. Relationship Between the Change in Discharge Coefficients and the Profile Peakness, $P_6$ for a Range of Beta Ratios.

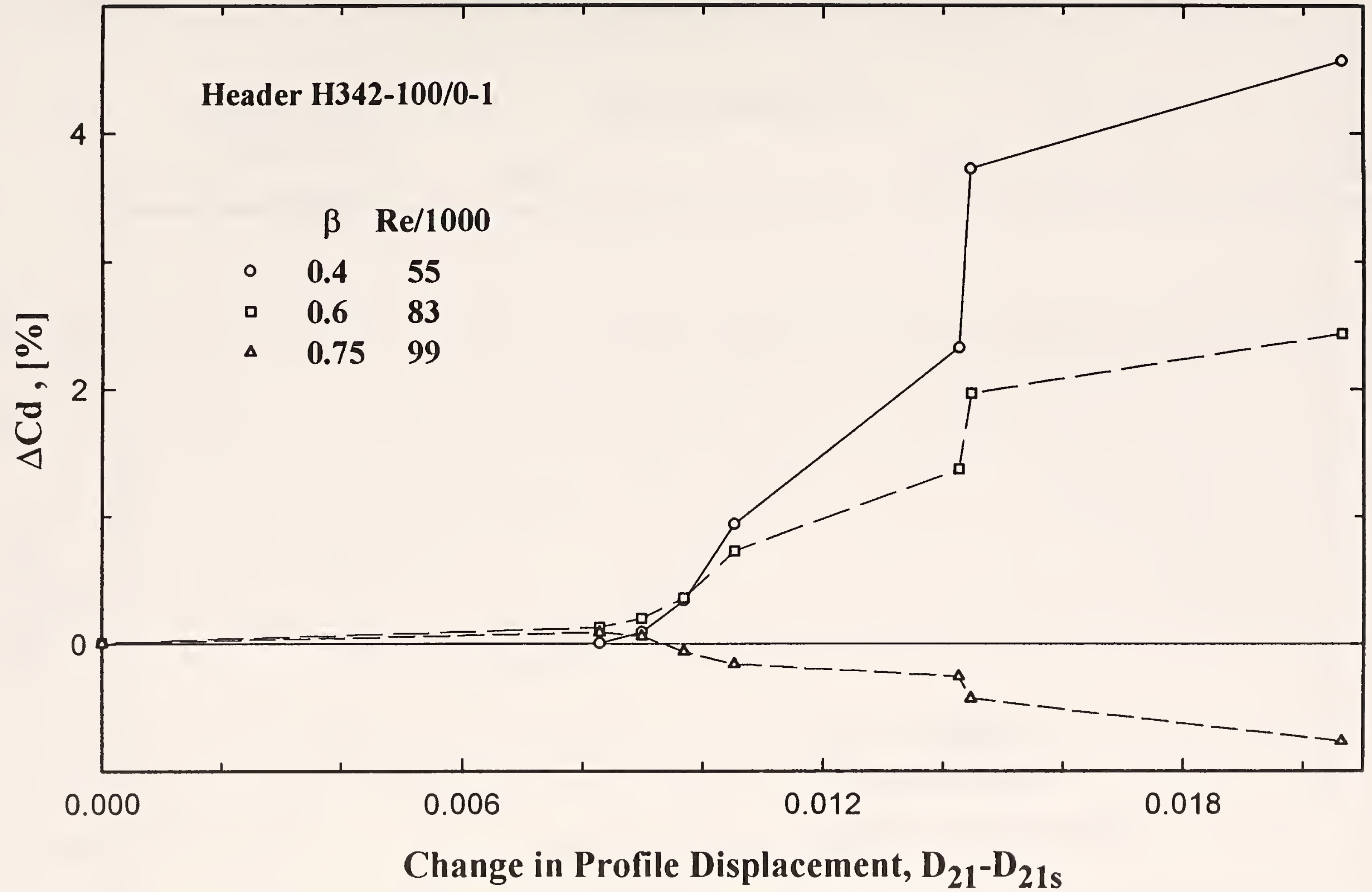


Figure 34. Relationship Between the Change in Discharge Coefficients and the Profile Displacement, $D_{21}$ for a Range of Beta Ratios.

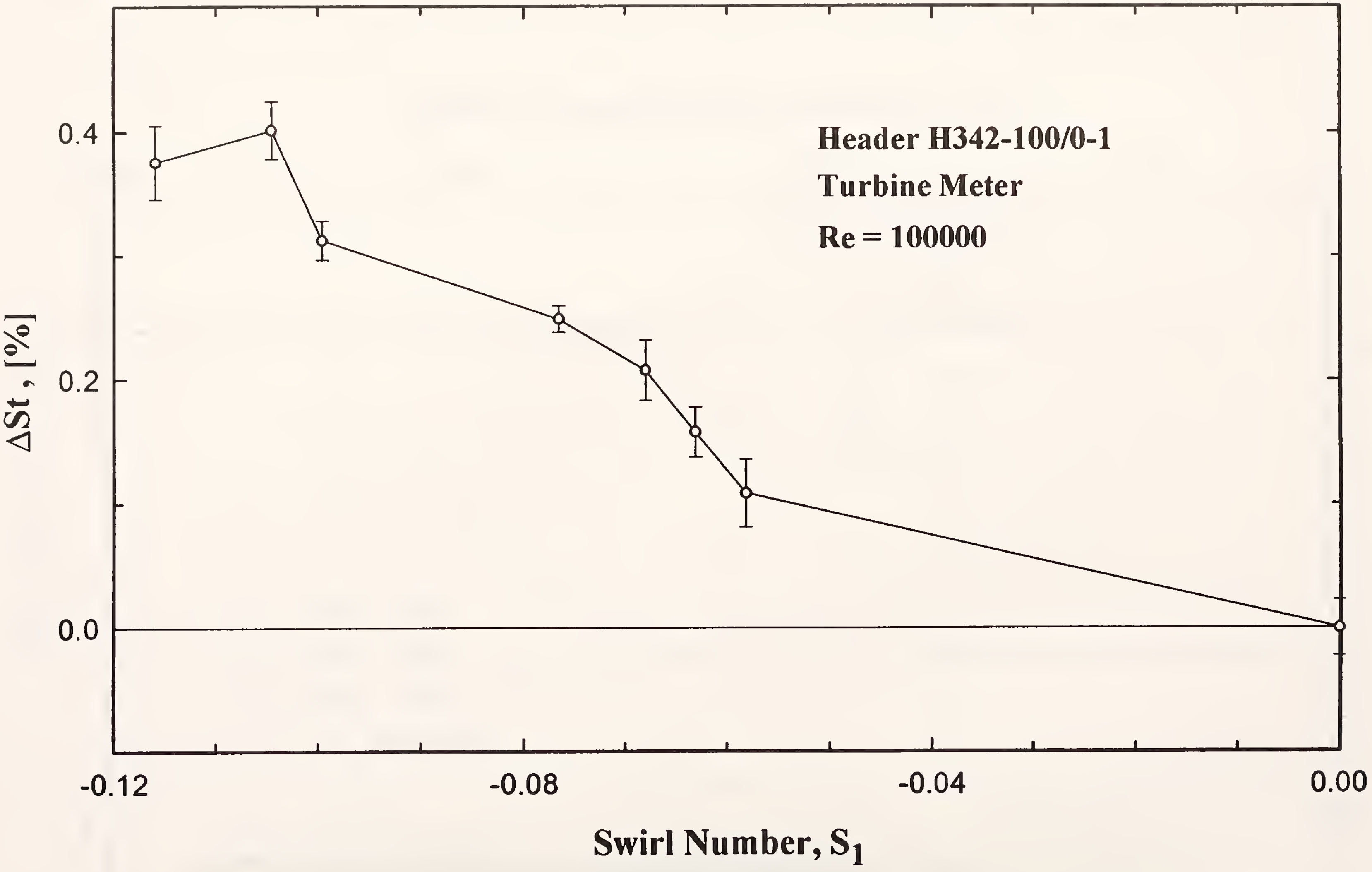


**Figure 35.** Relationship Between the Change in Meter Constant and the Swirl Number $S_1$ for a Turbine Meter.

StSa

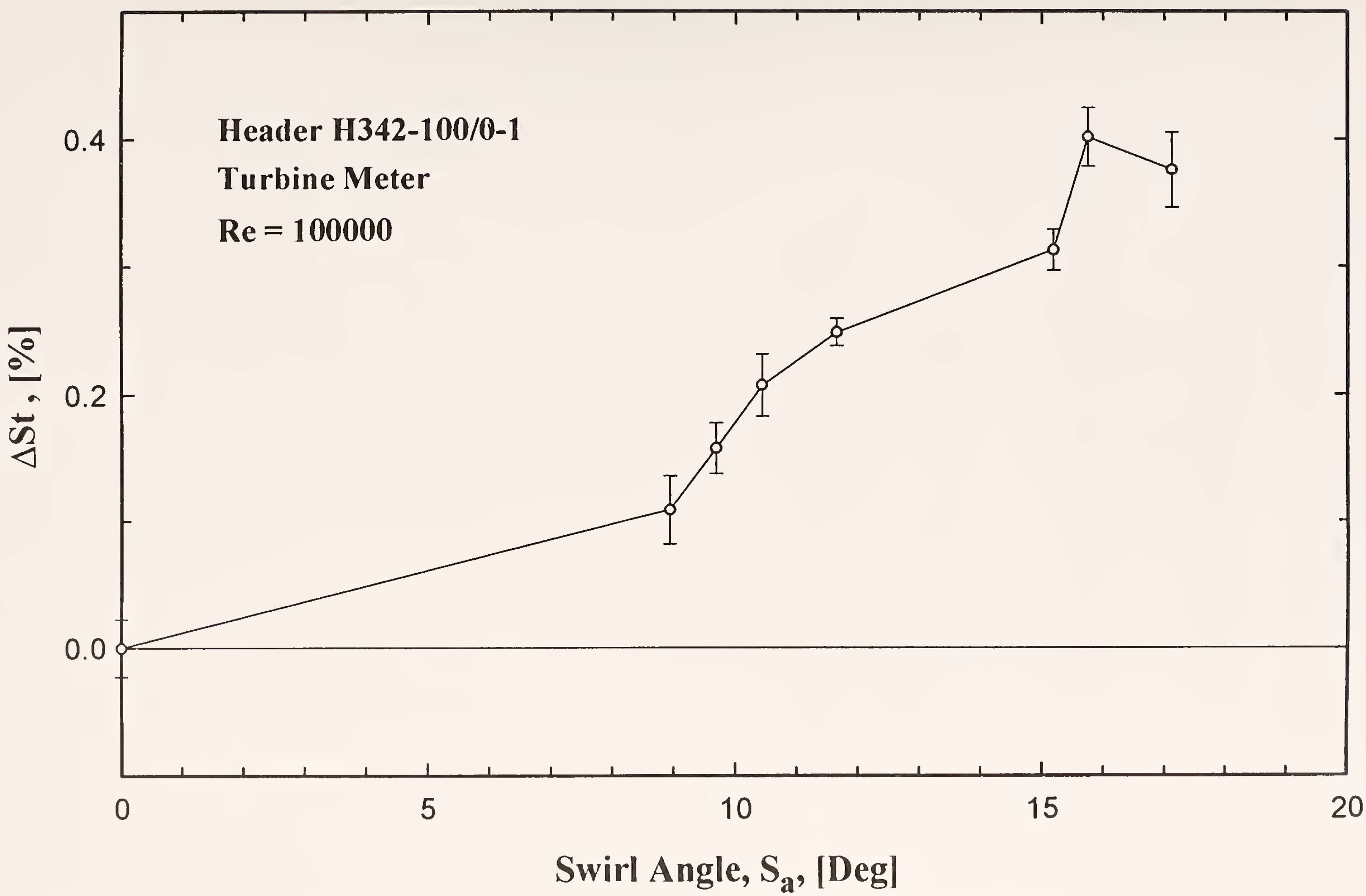


Figure 36. Relationship Between the Change in Meter Constant and the Swirl Angle $S_a$ for a Turbine Meter.

# APPENDIX A

## Orifice Flowmeter Performance for a Header H342-100/0-1

## Meters in the Outlet Pipe #1 with the Outlet #1 Opened and the Outlet #2 Closed

Water Temperature =21.5 °C
Gage Pressure = 138 kPa (20 PSI)
Water Density = 997.88 kg/m$^3$
Water Kinematic Viscosity = 9.71958*10$^{-7}$
Meter Tube Diameter, D= 52.5 mm (2.07")

## Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 4.66
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

|  |  | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100 At Pressure Tap Positions |  |  |  |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22254 | 2.21735 | 2.46876 | 2.38099 | 2.47832 |
| 2 | 22267 | 2.91114 | 3.03741 | 2.87481 | 2.91404 |
| 3 | 22239 | 2.66894 | 2.40543 | 2.73144 | 2.72680 |
| 4 | 22252 | 2.39069 | 2.60654 | 2.49238 | 2.55244 |
| 5 | 22260 | 2.52119 | 2.69128 | 2.64686 | 2.68923 |
| 6 | 28996 | 2.92524 | 3.30977 | 3.23613 | 3.26050 |
| 7 | 29010 | 3.31365 | 3.38375 | 3.30517 | 3.31159 |
| 8 | 28983 | 2.72436 | 2.80156 | 2.95478 | 2.93615 |
| 9 | 28987 | 2.98772 | 2.86294 | 2.85625 | 2.88440 |
| 10 | 29015 | 3.06438 | 3.03091 | 3.07123 | 3.07214 |
| 11 | 36022 | 3.51850 | 3.45872 | 3.44725 | 3.41335 |
| 12 | 36027 | 3.18225 | 3.24724 | 3.36292 | 3.25904 |
| 13 | 36027 | 3.70010 | 3.74319 | 3.67996 | 3.66751 |
| 14 | 36026 | 3.37315 | 3.37287 | 3.30492 | 3.51392 |
| 15 | 36030 | 3.58624 | 3.57562 | 3.53599 | 3.46016 |
| 16 | 44401 | 3.98834 | 4.06445 | 3.86915 | 4.00293 |
| 17 | 44397 | 4.14946 | 4.24777 | 4.07162 | 4.20567 |
| 18 | 44388 | 3.81401 | 3.90967 | 3.98238 | 3.93129 |
| 19 | 44392 | 4.24641 | 4.35382 | 4.25751 | 4.37527 |
| 20 | 44392 | 3.90774 | 4.03925 | 4.00253 | 3.98503 |
| 21 | 55387 | 4.32818 | 4.26649 | 4.41261 | 4.42798 |
| 22 | 55426 | 4.77427 | 4.82543 | 4.81613 | 4.78735 |
| 23 | 55444 | 4.60194 | 4.64174 | 4.59020 | 4.57629 |
| 24 | 55450 | 4.68273 | 4.72268 | 4.70349 | 4.67251 |
| 25 | 55406 | 4.44275 | 4.36497 | 4.35441 | 4.38021 |
|  |  | **** Average Data **** |  |  |  |
| 26 | 22254 | 2.54187 | 2.64189 | 2.62530 | 2.67216 |
| 27 | 28998 | 3.00308 | 3.07780 | 3.08472 | 3.09297 |
| 28 | 36027 | 3.47206 | 3.47953 | 3.46621 | 3.46280 |
| 29 | 44394 | 4.02119 | 4.12298 | 4.03663 | 4.10003 |
| 30 | 55423 | 4.56598 | 4.56428 | 4.57537 | 4.56887 |
|  |  | **** Standard Deviation **** |  |  |  |
| 31 | 22254 | 0.26505 | 0.24785 | 0.19447 | 0.16853 |
| 32 | 28998 | 0.21441 | 0.26067 | 0.18747 | 0.18985 |
| 33 | 36027 | 0.20060 | 0.19007 | 0.14797 | 0.14873 |
| 34 | 44394 | 0.17608 | 0.17661 | 0.14335 | 0.18576 |
| 35 | 55423 | 0.18004 | 0.23831 | 0.19336 | 0.16858 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 10.47
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22207 | 1.10831 | 1.13410 | 1.19658 | 1.28172 |
| 2 | 22210 | 1.61168 | 1.62592 | 1.60858 | 1.58858 |
| 3 | 22205 | 0.98933 | 1.02826 | 1.05520 | 1.16034 |
| 4 | 22190 | 1.74017 | 1.73385 | 1.66861 | 1.65187 |
| 5 | 22194 | 1.29939 | 1.43733 | 1.47422 | 1.40944 |
| 6 | 28917 | 1.97723 | 2.07859 | 2.09159 | 2.09085 |
| 7 | 28924 | 2.44723 | 2.32415 | 2.22626 | 2.17874 |
| 8 | 28926 | 1.73774 | 1.72496 | 1.71525 | 1.69979 |
| 9 | 28912 | 1.89451 | 1.91714 | 1.87106 | 1.85895 |
| 10 | 28905 | 2.19573 | 2.00527 | 1.97231 | 2.09858 |
| 11 | 36127 | 2.48006 | 2.52729 | 2.51847 | 2.53419 |
| 12 | 36109 | 2.61273 | 2.57550 | 2.68562 | 2.59272 |
| 13 | 36107 | 2.30467 | 2.40425 | 2.45308 | 2.42030 |
| 14 | 36103 | 2.77570 | 2.67051 | 2.79848 | 2.81832 |
| 15 | 36110 | 2.94427 | 2.81626 | 2.66631 | 2.64677 |
| 16 | 44367 | 3.22938 | 3.13736 | 3.08374 | 3.15374 |
| 17 | 44340 | 3.07580 | 2.90223 | 2.87236 | 2.84763 |
| 18 | 44328 | 2.96917 | 3.04606 | 2.98540 | 2.98200 |
| 19 | 44348 | 3.36299 | 3.32104 | 3.25223 | 3.31029 |
| 20 | 44327 | 2.82263 | 2.83570 | 2.80695 | 2.92834 |
| 21 | 55407 | 3.54186 | 3.61249 | 3.55625 | 3.60737 |
| 22 | 55422 | 3.70838 | 3.71974 | 3.67666 | 3.69093 |
| 23 | 55427 | 4.06524 | 3.99537 | 3.98780 | 3.82792 |
| 24 | 55409 | 3.94277 | 3.82484 | 3.80296 | 3.92745 |
| 25 | 55347 | 3.34943 | 3.51079 | 3.46582 | 3.51655 |
| | | **** Average Data **** | | | |
| 26 | 22201 | 1.34978 | 1.39189 | 1.40064 | 1.41839 |
| 27 | 28917 | 2.05049 | 2.01002 | 1.97530 | 1.98538 |
| 28 | 36111 | 2.62348 | 2.59877 | 2.62438 | 2.60245 |
| 29 | 44342 | 3.09198 | 3.04847 | 3.00013 | 3.04439 |
| 30 | 55402 | 3.72153 | 3.73264 | 3.69789 | 3.71404 |
| | | **** Standard Deviation **** | | | |
| 31 | 22201 | 0.32091 | 0.30522 | 0.26532 | 0.20551 |
| 32 | 28917 | 0.27660 | 0.21982 | 0.19686 | 0.19933 |
| 33 | 36111 | 0.24923 | 0.15490 | 0.13825 | 0.14711 |
| 34 | 44342 | 0.21208 | 0.19277 | 0.17622 | 0.18610 |
| 35 | 55402 | 0.29037 | 0.18767 | 0.20553 | 0.16513 |

Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 16.28
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], | $(C_d/C_{d,s}-1)*100$ | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22223 | 1.07119 | 0.96511 | 1.04199 | 0.99814 |
| 2 | 22226 | 0.69674 | 0.85578 | 0.72031 | 0.77210 |
| 3 | 22216 | 0.64360 | 0.65843 | 0.66424 | 0.73332 |
| 4 | 22221 | 0.87886 | 0.91889 | 0.92970 | 0.90299 |
| 5 | 22223 | 0.80493 | 0.77200 | 0.78812 | 0.67461 |
| 6 | 28949 | 0.94280 | 1.15928 | 0.92822 | 0.96741 |
| 7 | 28967 | 1.26460 | 1.10379 | 1.16983 | 1.12712 |
| 8 | 28947 | 1.12269 | 1.02180 | 1.10760 | 0.90745 |
| 9 | 28952 | 0.87444 | 0.94650 | 0.88576 | 1.10474 |
| 10 | 28978 | 1.04805 | 0.88665 | 1.00179 | 1.00963 |
| 11 | 36024 | 1.22731 | 1.29133 | 1.29795 | 1.20390 |
| 12 | 36005 | 1.38582 | 1.45254 | 1.41010 | 1.39632 |
| 13 | 35999 | 1.32045 | 1.41107 | 1.34964 | 1.37971 |
| 14 | 36019 | 1.56567 | 1.48579 | 1.46597 | 1.46347 |
| 15 | 36024 | 1.27124 | 1.24608 | 1.22831 | 1.29183 |
| 16 | 44403 | 1.63223 | 1.81560 | 1.81379 | 1.83703 |
| 17 | 44439 | 2.15395 | 1.89998 | 1.91468 | 1.93827 |
| 18 | 44408 | 1.77370 | 1.73419 | 1.73166 | 1.78910 |
| 19 | 44418 | 1.84657 | 1.95088 | 1.95042 | 1.96457 |
| 20 | 44456 | 1.96211 | 2.00198 | 2.00193 | 1.99727 |
| 21 | 55712 | 2.46356 | 2.38924 | 2.38192 | 2.38688 |
| 22 | 55716 | 2.33923 | 2.27311 | 2.22108 | 2.23142 |
| 23 | 55729 | 2.59883 | 2.45024 | 2.43242 | 2.44091 |
| 24 | 55773 | 2.16056 | 2.20842 | 2.16497 | 2.15174 |
| 25 | 55722 | 2.06545 | 2.15942 | 2.25857 | 2.18908 |
| | | **** Average Data **** | | | |
| 26 | 22222 | 0.81906 | 0.83404 | 0.82887 | 0.81624 |
| 27 | 28959 | 1.05053 | 1.02361 | 1.01865 | 1.02327 |
| 28 | 36014 | 1.35410 | 1.37736 | 1.35038 | 1.34705 |
| 29 | 44425 | 1.87372 | 1.88053 | 1.88250 | 1.90525 |
| 30 | 55730 | 2.32553 | 2.29609 | 2.29180 | 2.28000 |
| | | **** Standard Deviation **** | | | |
| 31 | 22222 | 0.16813 | 0.12197 | 0.15501 | 0.13181 |
| 32 | 28959 | 0.15293 | 0.11139 | 0.11921 | 0.09231 |
| 33 | 36014 | 0.13216 | 0.10400 | 0.09300 | 0.10082 |
| 34 | 44425 | 0.19686 | 0.10666 | 0.10859 | 0.08810 |
| 35 | 55730 | 0.21737 | 0.12190 | 0.11207 | 0.12703 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 27.9
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], ($C_d/C_{d,s}$-1)*100 | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22216 | 0.52338 | 0.49260 | 0.47787 | 0.48421 |
| 2 | 22212 | 0.31332 | 0.33806 | 0.38940 | 0.38459 |
| 3 | 22215 | 0.36885 | 0.42176 | 0.35405 | 0.41732 |
| 4 | 22222 | 0.40183 | 0.44880 | 0.49785 | 0.51076 |
| 5 | 22193 | 0.45386 | 0.37732 | 0.45935 | 0.45940 |
| 6 | 28868 | 0.49049 | 0.44709 | 0.44252 | 0.46785 |
| 7 | 28877 | 0.28516 | 0.37232 | 0.38646 | 0.40858 |
| 8 | 28887 | 0.53986 | 0.47106 | 0.47375 | 0.44934 |
| 9 | 28881 | 0.41774 | 0.45656 | 0.46318 | 0.39495 |
| 10 | 28871 | 0.35721 | 0.39024 | 0.40484 | 0.38262 |
| 11 | 36098 | 0.36688 | 0.44569 | 0.46176 | 0.45566 |
| 12 | 36106 | 0.53117 | 0.52423 | 0.52509 | 0.56194 |
| 13 | 36100 | 0.44207 | 0.48881 | 0.49450 | 0.51332 |
| 14 | 36117 | 0.56723 | 0.56783 | 0.56916 | 0.59034 |
| 15 | 36105 | 0.62971 | 0.54113 | 0.58431 | 0.60291 |
| 16 | 44434 | 0.54348 | 0.63991 | 0.66360 | 0.64470 |
| 17 | 44468 | 0.64615 | 0.78381 | 0.80170 | 0.81880 |
| 18 | 44477 | 0.71431 | 0.72084 | 0.74859 | 0.73700 |
| 19 | 44449 | 0.83612 | 0.74856 | 0.81331 | 0.75893 |
| 20 | 44457 | 0.75500 | 0.73349 | 0.71431 | 0.77906 |
| 21 | 55442 | 0.80103 | 0.90912 | 0.86165 | 0.87817 |
| 22 | 55272 | 0.93114 | 0.88405 | 0.95989 | 0.89784 |
| 23 | 55339 | 1.05897 | 0.99330 | 0.98812 | 0.98812 |
| 24 | 55638 | 0.99815 | 0.96157 | 0.91769 | 0.95958 |
| 25 | 55305 | 0.89665 | 0.86604 | 0.88548 | 0.84538 |
| | | **** Average Data **** | | | |
| 26 | 22211 | 0.41224 | 0.41571 | 0.43571 | 0.45125 |
| 27 | 28877 | 0.41810 | 0.42746 | 0.43416 | 0.42067 |
| 28 | 36105 | 0.50741 | 0.51352 | 0.52696 | 0.54483 |
| 29 | 44457 | 0.69900 | 0.72533 | 0.74830 | 0.74770 |
| 30 | 55399 | 0.93718 | 0.92282 | 0.92256 | 0.91382 |
| | | **** Standard Deviation **** | | | |
| 31 | 22211 | 0.08040 | 0.06020 | 0.06125 | 0.05070 |
| 32 | 28877 | 0.10176 | 0.04340 | 0.03740 | 0.03640 |
| 33 | 36105 | 0.10375 | 0.04740 | 0.05090 | 0.06050 |
| 34 | 44457 | 0.11078 | 0.05310 | 0.06100 | 0.06480 |
| 35 | 55399 | 0.09830 | 0.05250 | 0.05250 | 0.05810 |

## Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 and Beta = 0.3995169

Orifice Plate Axial Position Z/D= 39.52
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100 At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22167 | 0.31283 | 0.33627 | 0.21062 | 0.31371 |
| 2 | 22171 | 0.25423 | 0.22679 | 0.23874 | 0.21777 |
| 3 | 22191 | 0.30467 | 0.29478 | 0.32700 | 0.27224 |
| 4 | 22162 | 0.20455 | 0.24922 | 0.28552 | 0.25091 |
| 5 | 22179 | 0.27826 | 0.34614 | 0.34260 | 0.32680 |
| 6 | 28895 | 0.22694 | 0.17908 | 0.18355 | 0.28536 |
| 7 | 28898 | 0.15455 | 0.22832 | 0.24432 | 0.19774 |
| 8 | 28899 | 0.30840 | 0.25000 | 0.30670 | 0.26399 |
| 9 | 28899 | 0.21322 | 0.31284 | 0.26279 | 0.25082 |
| 10 | 28913 | 0.27014 | 0.28088 | 0.29937 | 0.22636 |
| 11 | 36082 | 0.29173 | 0.29537 | 0.28315 | 0.28198 |
| 12 | 36028 | 0.19447 | 0.17772 | 0.16921 | 0.24616 |
| 13 | 36061 | 0.24465 | 0.20917 | 0.22068 | 0.21966 |
| 14 | 36041 | 0.18868 | 0.24106 | 0.20795 | 0.19638 |
| 15 | 36042 | 0.21046 | 0.26108 | 0.24896 | 0.23347 |
| 16 | 44493 | 0.35448 | 0.23008 | 0.31625 | 0.26433 |
| 17 | 44492 | 0.26510 | 0.32576 | 0.30044 | 0.30053 |
| 18 | 44475 | 0.22168 | 0.29522 | 0.28504 | 0.28476 |
| 19 | 44476 | 0.29341 | 0.35597 | 0.33298 | 0.33012 |
| 20 | 44479 | 0.25027 | 0.26182 | 0.24428 | 0.30563 |
| 21 | 55601 | 0.41770 | 0.42807 | 0.41169 | 0.36221 |
| 22 | 55558 | 0.32434 | 0.32081 | 0.31535 | 0.31768 |
| 23 | 55582 | 0.30318 | 0.36090 | 0.35884 | 0.37620 |
| 24 | 55540 | 0.27028 | 0.28607 | 0.30243 | 0.32875 |
| 25 | 55580 | 0.37891 | 0.38293 | 0.37490 | 0.39448 |
| | | **** Average Data **** | | | |
| 26 | 22174 | 0.27091 | 0.29064 | 0.28090 | 0.27628 |
| 27 | 28901 | 0.23466 | 0.25022 | 0.25934 | 0.24485 |
| 28 | 36051 | 0.22600 | 0.23689 | 0.22600 | 0.23553 |
| 29 | 44483 | 0.27699 | 0.29377 | 0.29579 | 0.29708 |
| 30 | 55572 | 0.33888 | 0.35576 | 0.35264 | 0.35586 |
| | | **** Standard Deviation **** | | | |
| 31 | 22174 | 0.04360 | 0.05230 | 0.05620 | 0.04480 |
| 32 | 28901 | 0.05830 | 0.05090 | 0.04950 | 0.03300 |
| 33 | 36051 | 0.04240 | 0.04530 | 0.04268 | 0.03170 |
| 34 | 44483 | 0.05040 | 0.04900 | 0.03390 | 0.02456 |
| 35 | 55572 | 0.05890 | 0.05470 | 0.04430 | 0.03100 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 51.44
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

$\Delta C_d[\%]$, $(C_d/C_{d,s}-1)*100$
At Pressure Tap Positions

| No. | Re | 0° | 90° | 180° | 270° |
|---|---|---|---|---|---|
| 1 | 22116 | 0.01790 | 0.06820 | 0.05530 | 0.02090 |
| 2 | 22123 | 0.12171 | 0.12742 | 0.13837 | 0.05200 |
| 3 | 22093 | 0.11712 | 0.11320 | 0.10499 | 0.08380 |
| 4 | 22094 | 0.07360 | 0.15780 | 0.11687 | 0.10579 |
| 5 | 22115 | 0.10766 | 0.13758 | 0.15612 | 0.13722 |
| 6 | 28844 | 0.06000 | 0.06880 | 0.09251 | 0.06785 |
| 7 | 28855 | 0.02870 | 0.10993 | 0.11254 | 0.09180 |
| 8 | 28831 | 0.09050 | 0.02590 | 0.10600 | 0.05350 |
| 9 | 28830 | 0.09050 | 0.03780 | 0.06190 | 0.02990 |
| 10 | 28818 | 0.01540 | 0.05520 | 0.02490 | 0.01070 |
| 11 | 36118 | 0.10268 | 0.10119 | 0.06430 | 0.07880 |
| 12 | 36107 | 0.04840 | 0.03150 | 0.02300 | 0.02240 |
| 13 | 36139 | 0.08310 | 0.07110 | 0.10283 | 0.04850 |
| 14 | 36108 | 0.00853 | 0.02250 | 0.05520 | 0.00195 |
| 15 | 36123 | -0.03400 | 0.01170 | 0.00560 | 0.01540 |
| 16 | 44337 | -0.01300 | 0.04380 | 0.05100 | 0.05000 |
| 17 | 44357 | 0.03030 | 0.02910 | 0.10521 | 0.07577 |
| 18 | 44341 | 0.07980 | 0.09880 | 0.12516 | 0.10153 |
| 19 | 44358 | 0.13458 | 0.11626 | 0.11483 | 0.12054 |
| 20 | 44329 | 0.06870 | 0.07370 | 0.08560 | 0.04505 |
| 21 | 55597 | 0.11674 | 0.13138 | 0.14831 | 0.11052 |
| 22 | 55557 | 0.08540 | 0.08810 | 0.12019 | 0.06480 |
| 23 | 55600 | 0.17660 | 0.15310 | 0.16421 | 0.15075 |
| 24 | 55557 | 0.02900 | 0.04390 | 0.07840 | 0.05029 |
| 25 | 55563 | 0.05420 | 0.07400 | 0.06630 | 0.08460 |
| | | **** | Average Data | **** | |
| 26 | 22108 | 0.08760 | 0.12083 | 0.11434 | 0.07900 |
| 27 | 28836 | 0.05720 | 0.05950 | 0.07960 | 0.05080 |
| 28 | 36119 | 0.04170 | 0.04760 | 0.05020 | 0.03340 |
| 29 | 44344 | 0.06000 | 0.07230 | 0.09660 | 0.07880 |
| 30 | 55575 | 0.09260 | 0.09810 | 0.11547 | 0.09220 |
| | | **** | Standard Deviation | | **** |
| 31 | 22108 | 0.04330 | 0.03370 | 0.03840 | 0.04540 |
| 32 | 28836 | 0.03460 | 0.03240 | 0.03600 | 0.03150 |
| 33 | 36119 | 0.05550 | 0.03737 | 0.03769 | 0.03043 |
| 34 | 44344 | 0.05530 | 0.03640 | 0.02880 | 0.03220 |
| 35 | 55575 | 0.05600 | 0.04380 | 0.04240 | 0.03950 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 62.76
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], | $(C_d/C_{d,s}-1)$*100 | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22407 | 0.06190 | 0.02600 | 0.05068 | 0.05160 |
| 2 | 22403 | 0.07520 | 0.01570 | 0.04980 | 0.02590 |
| 3 | 22402 | 0.06710 | 0.07380 | 0.09020 | 0.06600 |
| 4 | 22409 | 0.04270 | 0.00285 | 0.12577 | 0.04667 |
| 5 | 22409 | 0.08210 | 0.06510 | 0.09050 | 0.01550 |
| 6 | 28881 | 0.00912 | 0.00264 | 0.02730 | 0.00353 |
| 7 | 28874 | 0.03370 | 0.02060 | 0.07240 | 0.03890 |
| 8 | 28859 | 0.00332 | 0.01500 | 0.03490 | -0.01600 |
| 9 | 28853 | 0.03570 | 0.00569 | 0.01750 | -0.03200 |
| 10 | 28866 | 0.01500 | 0.02198 | 0.02530 | -0.00960 |
| 11 | 36094 | -0.03800 | -0.03200 | -0.03246 | -0.05700 |
| 12 | 36051 | 0.05420 | -0.03200 | -0.05100 | -0.03700 |
| 13 | 36073 | -0.01300 | -0.00380 | -0.03800 | -0.00360 |
| 14 | 36088 | 0.00084 | 0.02220 | 0.02820 | -0.01900 |
| 15 | 36077 | 0.01820 | 0.02350 | 0.01090 | 0.01950 |
| 16 | 44370 | -0.04059 | -0.04900 | -0.07300 | -0.07900 |
| 17 | 44391 | 0.01240 | 0.04990 | 0.06490 | -0.01100 |
| 18 | 44410 | 0.03940 | 0.07300 | 0.05110 | 0.00644 |
| 19 | 44394 | -0.03300 | -0.00670 | -0.04200 | -0.02400 |
| 20 | 44392 | -0.00380 | -0.00930 | -0.00430 | -0.03200 |
| 21 | 55689 | 0.01760 | 0.01700 | -0.00088 | -0.01500 |
| 22 | 55665 | -0.04500 | -0.03800 | -0.01100 | -0.03900 |
| 23 | 55678 | 0.05500 | 0.02370 | 0.01500 | 0.00258 |
| 24 | 55678 | -0.00270 | 0.04400 | 0.04410 | -0.00930 |
| 25 | 55701 | -0.00810 | -0.01400 | -0.02400 | 0.02100 |
| | | **** | Average Data | **** | |
| 26 | 22406 | 0.06580 | 0.03670 | 0.08140 | 0.04130 |
| 27 | 28867 | 0.01960 | 0.01320 | 0.03550 | -0.00300 |
| 28 | 36077 | 0.00448 | -0.00440 | -0.01600 | -0.01900 |
| 29 | 44392 | -0.00510 | 0.01150 | -0.00069 | -0.02800 |
| 30 | 55682 | 0.00359 | 0.00695 | 0.00474 | -0.00780 |
| | | **** | Standard Deviation | | **** |
| 31 | 22406 | 0.01500 | 0.03120 | 0.03188 | 0.02060 |
| 32 | 28867 | 0.01460 | 0.00872 | 0.02150 | 0.02660 |
| 33 | 36077 | 0.03470 | 0.02740 | 0.03390 | 0.02960 |
| 34 | 44392 | 0.03270 | 0.04910 | 0.05890 | 0.03190 |
| 35 | 55682 | 0.03690 | 0.03230 | 0.02648 | 0.02240 |

Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 4.66
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

|  |  | $\Delta C_d$[%], ($C_d/C_{d,s}$-1)*100 |  |  |  |
|---|---|---|---|---|---|
|  |  | At Pressure Tap Positions |  |  |  |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36028 | 1.36545 | 1.39743 | 1.37017 | 1.30770 |
| 2 | 36017 | 1.56780 | 1.57884 | 1.59061 | 1.55478 |
| 3 | 36013 | 1.29779 | 1.24724 | 1.19750 | 1.20920 |
| 4 | 36032 | 1.44311 | 1.47478 | 1.46596 | 1.45146 |
| 5 | 36022 | 1.10768 | 1.27758 | 1.24906 | 1.18059 |
| 6 | 44431 | 1.82039 | 1.78618 | 1.77882 | 1.73741 |
| 7 | 44432 | 1.64515 | 1.61129 | 1.60411 | 1.56405 |
| 8 | 44462 | 1.56377 | 1.57004 | 1.54364 | 1.51784 |
| 9 | 44452 | 1.33835 | 1.49698 | 1.40241 | 1.43151 |
| 10 | 44444 | 1.39044 | 1.66363 | 1.50995 | 1.38832 |
| 11 | 55605 | 1.56934 | 1.72803 | 1.69744 | 1.93989 |
| 12 | 55611 | 1.70590 | 1.80689 | 1.79029 | 1.64734 |
| 13 | 55604 | 1.96137 | 1.91373 | 1.85492 | 1.89866 |
| 14 | 55617 | 1.86220 | 1.96229 | 1.91274 | 1.78566 |
| 15 | 55562 | 2.09217 | 2.03565 | 1.98827 | 2.02117 |
| 16 | 72363 | 2.33101 | 2.35875 | 2.41206 | 2.31024 |
| 17 | 72351 | 2.17723 | 2.15363 | 2.17600 | 2.23723 |
| 18 | 72333 | 1.91548 | 2.01617 | 2.07440 | 2.06026 |
| 19 | 72337 | 2.05852 | 2.16750 | 2.24091 | 2.16522 |
| 20 | 72334 | 2.28159 | 2.27652 | 2.31214 | 2.34528 |
| 21 | 83395 | 2.49984 | 2.45624 | 2.51401 | 2.64410 |
| 22 | 83302 | 2.33590 | 2.48751 | 2.43525 | 2.34451 |
| 23 | 83291 | 2.43738 | 2.43909 | 2.40620 | 2.47944 |
| 24 | 83295 | 2.50772 | 2.62249 | 2.56406 | 2.55097 |
| 25 | 83300 | 2.39850 | 2.40046 | 2.51805 | 2.51087 |
|  |  | **** Average Data **** |  |  |  |
| 26 | 36022 | 1.35636 | 1.39516 | 1.37466 | 1.34075 |
| 27 | 44444 | 1.55162 | 1.62562 | 1.56779 | 1.52782 |
| 28 | 55600 | 1.83821 | 1.88932 | 1.84874 | 1.85856 |
| 29 | 72344 | 2.15276 | 2.19452 | 2.24310 | 2.22365 |
| 30 | 83316 | 2.43587 | 2.48117 | 2.48752 | 2.50598 |
|  |  | **** Standard Deviation **** |  |  |  |
| 31 | 36022 | 0.17145 | 0.13760 | 0.15976 | 0.15974 |
| 32 | 44444 | 0.19547 | 0.10864 | 0.13903 | 0.13623 |
| 33 | 55600 | 0.20641 | 0.12282 | 0.11192 | 0.14569 |
| 34 | 72344 | 0.16882 | 0.13018 | 0.12861 | 0.11457 |
| 35 | 83316 | 0.07160 | 0.08510 | 0.06480 | 0.10909 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 10.47
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], | $(C_d/C_{d,s}-1)$*100 | | |
|---|---|---|---|---|---|
| | | At Pressure | Tap Positions | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36275 | 1.10447 | 1.15641 | 1.26462 | 1.28645 |
| 2 | 36276 | 1.01204 | 1.12660 | 1.03882 | 0.96757 |
| 3 | 36283 | 0.94889 | 1.03620 | 1.08444 | 1.07471 |
| 4 | 36245 | 1.33744 | 1.27247 | 1.45731 | 1.40606 |
| 5 | 36266 | 1.08837 | 1.10391 | 1.01821 | 1.12979 |
| 6 | 44457 | 1.12016 | 1.29493 | 1.22639 | 1.20178 |
| 7 | 44466 | 1.18234 | 1.18350 | 1.13359 | 1.14824 |
| 8 | 44444 | 1.29950 | 1.37632 | 1.50503 | 1.51483 |
| 9 | 44407 | 1.41005 | 1.44332 | 1.24879 | 1.28955 |
| 10 | 44441 | 1.55091 | 1.50356 | 1.55259 | 1.43481 |
| 11 | 55502 | 1.33332 | 1.45436 | 1.42015 | 1.50773 |
| 12 | 55483 | 1.55114 | 1.58766 | 1.59774 | 1.63221 |
| 13 | 55480 | 1.75814 | 1.67880 | 1.50786 | 1.47300 |
| 14 | 55502 | 1.59878 | 1.60952 | 1.64875 | 1.51880 |
| 15 | 55414 | 1.44135 | 1.50704 | 1.39470 | 1.38446 |
| 16 | 72449 | 1.95082 | 2.02154 | 1.89534 | 1.88514 |
| 17 | 72624 | 1.64913 | 1.75313 | 1.65464 | 1.59887 |
| 18 | 72639 | 1.73575 | 1.66234 | 1.74266 | 1.71787 |
| 19 | 72612 | 2.05190 | 1.93300 | 1.93383 | 1.82520 |
| 20 | 72268 | 1.80059 | 1.70878 | 1.61150 | 1.55790 |
| 21 | 83220 | 2.03786 | 1.89341 | 1.90473 | 1.91747 |
| 22 | 83200 | 2.04140 | 2.02005 | 1.98599 | 1.93295 |
| 23 | 83234 | 1.90294 | 1.75864 | 1.76882 | 1.77158 |
| 24 | 83249 | 2.14779 | 2.09570 | 2.11786 | 2.02013 |
| 25 | 83216 | 1.70285 | 1.91615 | 1.58479 | 1.68500 |
| | | **** | Average Data | **** | |
| 26 | 36269 | 1.09825 | 1.13913 | 1.17268 | 1.17292 |
| 27 | 44443 | 1.31259 | 1.36032 | 1.33329 | 1.31784 |
| 28 | 55476 | 1.53655 | 1.56748 | 1.51384 | 1.50325 |
| 29 | 72518 | 1.83764 | 1.81577 | 1.76760 | 1.71700 |
| 30 | 83224 | 1.96658 | 1.93679 | 1.87244 | 1.86543 |
| | | **** | Standard Deviation | | **** |
| 31 | 36269 | 0.14784 | 0.08600 | 0.18665 | 0.17409 |
| 32 | 44443 | 0.17380 | 0.12601 | 0.18449 | 0.15467 |
| 33 | 55476 | 0.16081 | 0.08790 | 0.10948 | 0.08890 |
| 34 | 72518 | 0.16304 | 0.15416 | 0.14219 | 0.14014 |
| 35 | 83224 | 0.17105 | 0.12866 | 0.20466 | 0.13463 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 16.28
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100 | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36143 | 0.76277 | 0.80401 | 0.90481 | 0.74870 |
| 2 | 36146 | 0.72789 | 0.75917 | 0.75721 | 0.84705 |
| 3 | 36116 | 0.93188 | 0.91083 | 0.99614 | 0.96978 |
| 4 | 36124 | 0.58714 | 0.95476 | 0.95389 | 0.77103 |
| 5 | 36142 | 0.84189 | 0.81922 | 0.73633 | 0.78756 |
| 6 | 44304 | 0.94250 | 1.05849 | 1.09924 | 1.01901 |
| 7 | 44313 | 0.86506 | 1.00137 | 0.96624 | 0.75073 |
| 8 | 44358 | 0.79601 | 0.93932 | 0.91333 | 0.83123 |
| 9 | 44347 | 0.72118 | 1.07431 | 0.85050 | 0.71367 |
| 10 | 44326 | 1.05776 | 0.96487 | 1.03422 | 1.12190 |
| 11 | 55636 | 0.93879 | 1.09096 | 1.08263 | 0.90163 |
| 12 | 55604 | 1.07417 | 1.16602 | 1.21325 | 1.17405 |
| 13 | 55579 | 1.09222 | 1.20045 | 1.22998 | 1.05334 |
| 14 | 55552 | 0.83090 | 0.96484 | 0.92844 | 0.85274 |
| 15 | 55570 | 1.11878 | 1.13397 | 1.13027 | 1.09511 |
| 16 | 73181 | 1.07443 | 1.27557 | 1.17948 | 1.05941 |
| 17 | 73168 | 1.26203 | 1.31036 | 1.38292 | 1.23124 |
| 18 | 73147 | 1.14232 | 1.19404 | 1.20932 | 1.15549 |
| 19 | 73122 | 1.36739 | 1.34863 | 1.36640 | 1.20071 |
| 20 | 72821 | 1.29882 | 1.40439 | 1.42641 | 1.34707 |
| 21 | 83415 | 1.44491 | 1.46193 | 1.51155 | 1.31534 |
| 22 | 83466 | 1.39093 | 1.40775 | 1.37232 | 1.37517 |
| 23 | 83456 | 1.51312 | 1.50753 | 1.57737 | 1.42493 |
| 24 | 83378 | 1.25317 | 1.37149 | 1.31118 | 1.25561 |
| 25 | 83380 | 1.25024 | 1.27688 | 1.30540 | 1.21992 |
| | | **** | Average Data | **** | |
| 26 | 36134 | 0.77031 | 0.84960 | 0.86967 | 0.82483 |
| 27 | 44330 | 0.87650 | 1.00768 | 0.97271 | 0.88731 |
| 28 | 55588 | 1.01096 | 1.11124 | 1.11691 | 1.01537 |
| 29 | 73088 | 1.22900 | 1.30661 | 1.31292 | 1.19879 |
| 30 | 83419 | 1.37047 | 1.40512 | 1.41556 | 1.31820 |
| | | **** | Standard Deviation | | **** |
| 31 | 36134 | 0.12911 | 0.08080 | 0.11722 | 0.08900 |
| 32 | 44330 | 0.13059 | 0.05840 | 0.09820 | 0.17648 |
| 33 | 55588 | 0.12228 | 0.09110 | 0.12120 | 0.13447 |
| 34 | 73088 | 0.11977 | 0.08050 | 0.11217 | 0.10699 |
| 35 | 83419 | 0.11636 | 0.08810 | 0.12249 | 0.08350 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 27.9
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

|  |  | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions |  |  |  |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36133 | 0.25960 | 0.43036 | 0.48900 | 0.40821 |
| 2 | 36146 | 0.46394 | 0.48063 | 0.57467 | 0.32998 |
| 3 | 36150 | 0.29931 | 0.40420 | 0.40176 | 0.43031 |
| 4 | 36132 | 0.51785 | 0.57963 | 0.60282 | 0.60209 |
| 5 | 36114 | 0.33151 | 0.34340 | 0.38775 | 0.28900 |
| 6 | 44771 | 0.32306 | 0.46177 | 0.47957 | 0.43469 |
| 7 | 44791 | 0.49797 | 0.52316 | 0.58915 | 0.52410 |
| 8 | 44778 | 0.43834 | 0.59688 | 0.45665 | 0.36560 |
| 9 | 44783 | 0.39866 | 0.56024 | 0.43984 | 0.34402 |
| 10 | 44803 | 0.44599 | 0.66911 | 0.60418 | 0.48913 |
| 11 | 55780 | 0.54680 | 0.62217 | 0.62999 | 0.53088 |
| 12 | 55767 | 0.56091 | 0.57130 | 0.54468 | 0.47442 |
| 13 | 55774 | 0.66597 | 0.65672 | 0.71825 | 0.64392 |
| 14 | 55735 | 0.40639 | 0.47944 | 0.47217 | 0.40026 |
| 15 | 55678 | 0.41752 | 0.45674 | 0.34290 | 0.33651 |
| 16 | 72042 | 0.79376 | 0.77214 | 0.84126 | 0.75407 |
| 17 | 72232 | 0.67613 | 0.68810 | 0.70166 | 0.64450 |
| 18 | 72269 | 0.59345 | 0.63464 | 0.65990 | 0.62016 |
| 19 | 72272 | 0.56370 | 0.69492 | 0.59495 | 0.48663 |
| 20 | 72298 | 0.57498 | 0.60889 | 0.66735 | 0.56060 |
| 21 | 83231 | 0.73368 | 0.74752 | 0.83318 | 0.75736 |
| 22 | 83249 | 0.59633 | 0.62272 | 0.64387 | 0.63043 |
| 23 | 83283 | 0.75029 | 0.70056 | 0.70244 | 0.59329 |
| 24 | 83242 | 0.74846 | 0.80571 | 0.74924 | 0.70824 |
| 25 | 83191 | 0.80052 | 0.76939 | 0.79550 | 0.69691 |
|  |  | **** Average Data **** |  |  |  |
| 26 | 36135 | 0.37444 | 0.44765 | 0.49119 | 0.41191 |
| 27 | 44785 | 0.42080 | 0.56223 | 0.51387 | 0.43150 |
| 28 | 55747 | 0.51952 | 0.55727 | 0.54161 | 0.47720 |
| 29 | 72222 | 0.64040 | 0.67974 | 0.69302 | 0.61319 |
| 30 | 83239 | 0.72586 | 0.72919 | 0.74485 | 0.67726 |
|  |  | **** Standard Deviation **** |  |  |  |
| 31 | 36135 | 0.11093 | 0.08870 | 0.09760 | 0.12070 |
| 32 | 44785 | 0.06490 | 0.07770 | 0.07690 | 0.07720 |
| 33 | 55747 | 0.10798 | 0.08660 | 0.14369 | 0.11815 |
| 34 | 72222 | 0.09775 | 0.06430 | 0.09270 | 0.10078 |
| 35 | 83239 | 0.07680 | 0.07080 | 0.07500 | 0.06546 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 39.52
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

$\Delta C_d[\%]$, $(C_d/C_{d,s}-1)*100$

| | | At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36251 | 0.07230 | 0.18774 | 0.15712 | 0.06552 |
| 2 | 36265 | 0.10127 | 0.22263 | 0.17432 | 0.17739 |
| 3 | 36258 | 0.13433 | 0.20460 | 0.22777 | 0.26297 |
| 4 | 36253 | 0.14925 | 0.22683 | 0.21370 | 0.30427 |
| 5 | 36264 | 0.24929 | 0.26846 | 0.27665 | 0.35017 |
| 6 | 44344 | 0.09470 | 0.29999 | 0.17659 | 0.24654 |
| 7 | 44336 | 0.03170 | 0.23813 | 0.14866 | 0.07240 |
| 8 | 44335 | 0.22476 | 0.31298 | 0.21970 | 0.20837 |
| 9 | 44360 | 0.16615 | 0.32984 | 0.20030 | 0.16320 |
| 10 | 44347 | 0.14515 | 0.30851 | 0.13930 | 0.08177 |
| 11 | 55701 | 0.20706 | 0.31794 | 0.28392 | 0.22613 |
| 12 | 55709 | 0.13696 | 0.19276 | 0.15238 | 0.19725 |
| 13 | 55714 | 0.15688 | 0.24550 | 0.16303 | 0.11341 |
| 14 | 55675 | 0.08050 | 0.21660 | 0.16603 | 0.15545 |
| 15 | 55731 | 0.17687 | 0.27691 | 0.26388 | 0.17068 |
| 16 | 72000 | 0.17759 | 0.20874 | 0.22660 | 0.15182 |
| 17 | 72064 | 0.38357 | 0.45993 | 0.43271 | 0.34766 |
| 18 | 72046 | 0.23951 | 0.27270 | 0.28221 | 0.19400 |
| 19 | 72044 | 0.21636 | 0.25507 | 0.23996 | 0.18795 |
| 20 | 72077 | 0.37687 | 0.40409 | 0.39339 | 0.39216 |
| 21 | 83269 | 0.35813 | 0.41344 | 0.39503 | 0.38688 |
| 22 | 83254 | 0.41025 | 0.49498 | 0.47528 | 0.49569 |
| 23 | 83247 | 0.42801 | 0.49746 | 0.42961 | 0.43478 |
| 24 | 83191 | 0.32760 | 0.39218 | 0.28222 | 0.30665 |
| 25 | 83214 | 0.28049 | 0.31585 | 0.29311 | 0.26557 |
| | | **** Average Data **** | | | |
| 26 | 36258 | 0.14129 | 0.22206 | 0.20992 | 0.23207 |
| 27 | 44345 | 0.13248 | 0.29789 | 0.17690 | 0.15445 |
| 28 | 55706 | 0.15165 | 0.24994 | 0.20585 | 0.17257 |
| 29 | 72046 | 0.27878 | 0.32011 | 0.31498 | 0.25471 |
| 30 | 83235 | 0.36089 | 0.42278 | 0.37504 | 0.37790 |
| | | **** Standard Deviation **** | | | |
| 31 | 36258 | 0.06730 | 0.03020 | 0.04600 | 0.11269 |
| 32 | 44345 | 0.07310 | 0.03502 | 0.03390 | 0.07660 |
| 33 | 55706 | 0.04730 | 0.04930 | 0.06260 | 0.04270 |
| 34 | 72046 | 0.09490 | 0.10630 | 0.09260 | 0.10720 |
| 35 | 83235 | 0.06002 | 0.07600 | 0.08450 | 0.09310 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 51.14
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36333 | -0.01500 | -0.00130 | 0.05560 | -0.00360 |
| 2 | 36323 | 0.08900 | 0.12905 | 0.12339 | 0.15311 |
| 3 | 36316 | 0.03050 | 0.14168 | 0.11982 | 0.06840 |
| 4 | 36314 | 0.05550 | 0.02930 | -0.05800 | -0.04300 |
| 5 | 36290 | 0.06780 | -0.05200 | 0.03510 | 0.12140 |
| 6 | 44362 | 0.07650 | 0.08700 | -0.04500 | -0.02900 |
| 7 | 44364 | 0.05180 | 0.13662 | 0.08880 | 0.12268 |
| 8 | 44336 | 0.03460 | 0.07770 | 0.02390 | 0.07980 |
| 9 | 44308 | -0.02720 | 0.14035 | 0.00555 | -0.08141 |
| 10 | 44302 | 0.01860 | 0.27723 | 0.08290 | 0.04110 |
| 11 | 55741 | 0.07180 | 0.12351 | 0.13483 | 0.11501 |
| 12 | 55740 | 0.04280 | 0.10810 | 0.00280 | 0.04318 |
| 13 | 55703 | -0.03300 | 0.09060 | 0.06420 | -0.02700 |
| 14 | 55725 | 0.02450 | 0.11059 | 0.04740 | -0.06083 |
| 15 | 55715 | 0.00222 | 0.08496 | 0.02850 | -0.10340 |
| 16 | 72225 | 0.14217 | 0.21729 | 0.14455 | 0.13583 |
| 17 | 72236 | 0.14041 | 0.16806 | 0.23378 | 0.11151 |
| 18 | 72195 | 0.12362 | 0.13300 | 0.15415 | 0.04940 |
| 19 | 72240 | 0.15051 | 0.20693 | 0.18063 | 0.10701 |
| 20 | 72220 | 0.06590 | 0.11617 | 0.15088 | 0.02470 |
| 21 | 83512 | 0.17292 | 0.19265 | 0.18078 | 0.27464 |
| 22 | 83563 | 0.23601 | 0.33619 | 0.28863 | 0.09460 |
| 23 | 83545 | 0.22535 | 0.26750 | 0.21653 | 0.17725 |
| 24 | 83395 | 0.20784 | 0.27634 | 0.16024 | 0.15638 |
| 25 | 83363 | 0.14518 | 0.17900 | 0.20678 | 0.13693 |
| | | **** | Average Data | **** | |
| 26 | 36315 | 0.04570 | 0.04930 | 0.05530 | 0.05940 |
| 27 | 44334 | 0.03090 | 0.14379 | 0.03130 | 0.02670 |
| 28 | 55725 | 0.02170 | 0.10356 | 0.05560 | -0.00670 |
| 29 | 72223 | 0.12453 | 0.16829 | 0.17280 | 0.08571 |
| 30 | 83476 | 0.19746 | 0.25033 | 0.21058 | 0.16795 |
| | | **** | Standard Deviation | | **** |
| 31 | 36315 | 0.04040 | 0.08370 | 0.07300 | 0.08240 |
| 32 | 44334 | 0.03850 | 0.08010 | 0.05590 | 0.08100 |
| 33 | 55725 | 0.03940 | 0.01540 | 0.04978 | 0.08640 |
| 34 | 72223 | 0.03410 | 0.04420 | 0.03660 | 0.04640 |
| 35 | 83476 | 0.03710 | 0.06420 | 0.04830 | 0.06690 |

## Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 and Beta = 0.5990338

Orifice Plate Axial Position Z/D= 62.76
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36262 | -0.05058 | -0.03000 | 0.00712 | -0.07600 |
| 2 | 36273 | 0.00596 | 0.04990 | 0.04170 | 0.08730 |
| 3 | 36262 | 0.06590 | 0.21764 | 0.23647 | -0.03600 |
| 4 | 36248 | -0.08200 | 0.06770 | 0.07080 | 0.03350 |
| 5 | 36255 | 0.00003 | 0.14946 | 0.03750 | 0.11419 |
| 6 | 44423 | 0.04910 | 0.13686 | 0.05170 | 0.05360 |
| 7 | 44408 | -0.01300 | 0.15609 | 0.01360 | 0.00442 |
| 8 | 44413 | 0.00139 | 0.07520 | -0.01300 | -0.01400 |
| 9 | 44407 | -0.05500 | 0.12733 | -0.00490 | -0.04300 |
| 10 | 44442 | 0.08730 | 0.13475 | 0.01300 | -0.09000 |
| 11 | 55562 | 0.06463 | 0.06100 | 0.05630 | -0.03300 |
| 12 | 55540 | -0.03600 | 0.05920 | 0.04850 | -0.07995 |
| 13 | 55531 | 0.00434 | 0.01380 | -0.03200 | -0.09300 |
| 14 | 55578 | -0.02300 | -0.01900 | 0.01620 | -0.11082 |
| 15 | 55550 | 0.01500 | 0.04430 | 0.02550 | -0.14984 |
| 16 | 72179 | 0.05920 | 0.15400 | 0.11993 | 0.02920 |
| 17 | 72198 | 0.10946 | 0.09860 | 0.13200 | 0.00795 |
| 18 | 72111 | -0.01600 | 0.00314 | 0.04400 | -0.01600 |
| 19 | 72176 | 0.04400 | 0.03600 | 0.04520 | -0.03900 |
| 20 | 72180 | 0.03030 | 0.08980 | 0.03920 | -0.06700 |
| 21 | 83303 | 0.14000 | 0.12492 | 0.13170 | 0.14987 |
| 22 | 83340 | 0.20116 | 0.19131 | 0.16961 | 0.16043 |
| 23 | 83312 | 0.14869 | 0.16026 | 0.15291 | 0.02520 |
| 24 | 83308 | 0.08660 | 0.14773 | 0.13447 | 0.09450 |
| 25 | 83286 | 0.06440 | 0.06670 | 0.06760 | 0.00851 |
| | | **** Average Data **** | | | |
| 26 | 36260 | -0.01200 | 0.09090 | 0.07870 | 0.02452 |
| 27 | 44419 | 0.01390 | 0.12606 | 0.01220 | -0.01791 |
| 28 | 55552 | 0.00493 | 0.03212 | 0.02280 | -0.09300 |
| 29 | 72169 | 0.04560 | 0.07630 | 0.07620 | -0.01700 |
| 30 | 83310 | 0.12816 | 0.13818 | 0.13126 | 0.08770 |
| | | **** Standard Deviation **** | | | |
| 31 | 36260 | 0.05670 | 0.09540 | 0.09100 | 0.08040 |
| 32 | 44419 | 0.05520 | 0.03030 | 0.02492 | 0.05380 |
| 33 | 55552 | 0.03920 | 0.03430 | 0.03480 | 0.04280 |
| 34 | 72169 | 0.04510 | 0.05818 | 0.04540 | 0.03790 |
| 35 | 83310 | 0.05380 | 0.04640 | 0.03850 | 0.06940 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 4.66
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

|  |  | $\Delta C_d$[%], | $(C_d/C_{d,s}-1)$*100 |  |  |
|---|---|---|---|---|---|
|  |  | At Pressure Tap Positions |  |  |  |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44577 | -2.23229 | -2.43816 | -2.05832 | -2.00458 |
| 2 | 44588 | -2.11286 | -1.91469 | -1.77927 | -1.68924 |
| 3 | 44590 | -1.85141 | -2.28704 | -1.89954 | -1.89527 |
| 4 | 44594 | -1.94187 | -1.98837 | -1.85295 | -1.77782 |
| 5 | 44607 | -2.00198 | -2.10498 | -2.16868 | -2.11317 |
| 6 | 55612 | -1.98319 | -1.78699 | -1.69830 | -1.88171 |
| 7 | 55584 | -1.82557 | -2.15944 | -1.67392 | -1.45427 |
| 8 | 55589 | -1.65151 | -2.33904 | -1.88782 | -1.60353 |
| 9 | 55589 | -1.52127 | -1.54599 | -1.59300 | -1.56117 |
| 10 | 55551 | -2.07183 | -1.72204 | -1.48447 | -1.95243 |
| 11 | 72159 | -1.21514 | -1.56072 | -1.67926 | -1.43608 |
| 12 | 72162 | -1.66434 | -1.70005 | -1.48238 | -1.57799 |
| 13 | 72156 | -1.31709 | -1.30475 | -1.35995 | -1.49726 |
| 14 | 72155 | -1.49345 | -1.69593 | -1.26327 | -1.24701 |
| 15 | 72138 | -1.08043 | -1.54194 | -1.53818 | -1.11455 |
| 16 | 83097 | -0.90598 | -1.29370 | -1.18598 | -0.96966 |
| 17 | 83084 | -1.33706 | -1.50448 | -1.33699 | -1.31938 |
| 18 | 83054 | -0.77482 | -1.36544 | -1.53637 | -1.17948 |
| 19 | 83047 | -1.06965 | -0.85308 | -0.81893 | -1.09805 |
| 20 | 83008 | -1.17856 | -1.42794 | -1.19850 | -1.22937 |
| 21 | 98742 | -0.81534 | -1.32792 | -1.07123 | -0.91440 |
| 22 | 98729 | -0.63788 | -0.65394 | -0.91503 | -0.87165 |
| 23 | 98731 | -0.44908 | -0.13711 | -0.45196 | -0.46979 |
| 24 | 98747 | -0.99317 | -0.80241 | -0.42392 | -0.78505 |
| 25 | 98783 | -0.93325 | -1.30058 | -0.83608 | -0.75695 |
|  |  | **** | Average Data | **** |  |
| 26 | 44591 | -2.02808 | -2.14664 | -1.95175 | -1.89602 |
| 27 | 55585 | -1.81067 | -1.91070 | -1.66752 | -1.69062 |
| 28 | 72154 | -1.35409 | -1.56068 | -1.46461 | -1.37458 |
| 29 | 83058 | -1.05321 | -1.28894 | -1.21537 | -1.15918 |
| 30 | 98746 | -0.76574 | -0.84439 | -0.73964 | -0.75957 |
|  |  | **** | Standard Deviation |  | **** |
| 31 | 44591 | 0.14834 | 0.21508 | 0.15872 | 0.17014 |
| 32 | 55585 | 0.22748 | 0.32765 | 0.14912 | 0.21509 |
| 33 | 72154 | 0.22994 | 0.16094 | 0.16069 | 0.18997 |
| 34 | 83058 | 0.22113 | 0.25581 | 0.26285 | 0.13269 |
| 35 | 98746 | 0.22320 | 0.49525 | 0.28834 | 0.17408 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 10.47
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$<br>At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44440 | -1.14914 | -1.11713 | -0.99718 | -1.06717 |
| 2 | 44468 | -1.05504 | -0.83307 | -1.05530 | -1.15707 |
| 3 | 44453 | -0.92090 | -1.03583 | -1.10645 | -0.52306 |
| 4 | 44466 | -0.78167 | -0.95454 | -1.06270 | -0.86685 |
| 5 | 44401 | -0.97098 | -0.91581 | -1.01355 | -1.21144 |
| 6 | 55589 | -0.77091 | -0.45285 | -0.86418 | -1.00724 |
| 7 | 55620 | -0.83592 | -0.68671 | -1.07930 | -0.93320 |
| 8 | 55582 | -1.08995 | -0.77832 | -0.75796 | -1.09780 |
| 9 | 55555 | -0.91857 | -0.87296 | -1.28637 | -1.14264 |
| 10 | 55594 | -0.60021 | -0.73011 | -1.09632 | -0.82665 |
| 11 | 72264 | -0.48630 | -0.60401 | -1.00196 | -0.76787 |
| 12 | 72233 | -0.67238 | -0.69630 | -0.80550 | -0.56397 |
| 13 | 72291 | -0.82834 | -0.28423 | -0.64461 | -1.06177 |
| 14 | 72239 | -0.59080 | -0.90331 | -0.88495 | -0.83692 |
| 15 | 72231 | -0.75652 | -0.94811 | -1.06055 | -0.80903 |
| 16 | 83228 | -0.41046 | -0.72845 | -0.75977 | -0.78862 |
| 17 | 83186 | -0.68508 | -0.51181 | -0.87529 | -1.17556 |
| 18 | 83206 | -0.53728 | -0.34083 | -0.81509 | -0.86791 |
| 19 | 83229 | -0.62272 | -0.77423 | -0.68397 | -0.54215 |
| 20 | 83180 | -0.57892 | -0.81220 | -0.95002 | -0.43898 |
| 21 | 98869 | -0.44771 | -0.35823 | -0.62827 | -0.68932 |
| 22 | 98928 | -0.26306 | -0.20555 | -0.53561 | -0.42098 |
| 23 | 98897 | -0.35373 | -0.37380 | -0.69455 | -0.54868 |
| 24 | 98930 | -0.50993 | -0.60015 | -0.45144 | -0.64934 |
| 25 | 98889 | -0.56846 | -0.59378 | -0.43941 | -0.47819 |
| | | **** Average Data **** | | | |
| 26 | 44446 | -0.97554 | -0.97127 | -1.04706 | -0.96511 |
| 27 | 55588 | -0.84311 | -0.70420 | -1.01684 | -1.00151 |
| 28 | 72252 | -0.66688 | -0.68719 | -0.87952 | -0.80791 |
| 29 | 83206 | -0.56690 | -0.63350 | -0.81684 | -0.76264 |
| 30 | 98903 | -0.42859 | -0.42632 | -0.54986 | -0.55730 |
| | | **** Standard Deviation **** | | | |
| 31 | 44446 | 0.13862 | 0.10934 | 0.04360 | 0.27944 |
| 32 | 55588 | 0.18070 | 0.15637 | 0.20794 | 0.12655 |
| 33 | 72252 | 0.13478 | 0.26604 | 0.16434 | 0.17816 |
| 34 | 83206 | 0.10295 | 0.20083 | 0.10214 | 0.28959 |
| 35 | 98903 | 0.12188 | 0.16910 | 0.11070 | 0.11257 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 16.28
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

|  |  | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions |  |  |  |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44662 | -0.67127 | -0.76623 | -0.23484 | -0.46506 |
| 2 | 44650 | -0.59837 | -0.70060 | -0.65105 | -0.69645 |
| 3 | 44688 | -0.50365 | -0.67055 | -0.73284 | -0.51860 |
| 4 | 44674 | -0.80502 | -0.60016 | -0.66796 | -0.40931 |
| 5 | 44678 | -0.43610 | -0.54584 | -0.54349 | -0.61839 |
| 6 | 55348 | -0.67252 | -0.67359 | -0.42589 | -0.50203 |
| 7 | 55312 | -0.45205 | -0.62847 | -0.74522 | -0.55042 |
| 8 | 55315 | -0.59075 | -0.56736 | -0.54781 | -0.59164 |
| 9 | 55306 | -0.71969 | -0.47575 | -0.57762 | -0.71536 |
| 10 | 55287 | -0.51904 | -0.73017 | -0.85109 | -0.66063 |
| 11 | 72444 | -0.52261 | -0.47359 | -0.48919 | -0.40105 |
| 12 | 72455 | -0.05500 | -0.38848 | -0.89413 | -0.51910 |
| 13 | 72444 | -0.35713 | -0.71195 | -0.54587 | -0.35311 |
| 14 | 72471 | -0.62651 | -0.60245 | -0.38878 | -0.48713 |
| 15 | 72462 | -0.63115 | -0.54815 | -0.40611 | -0.27763 |
| 16 | 83251 | -0.35794 | -0.41946 | -0.39221 | -0.40975 |
| 17 | 83217 | -0.47243 | -0.28968 | -0.40257 | -0.50654 |
| 18 | 83199 | -0.42471 | -0.50596 | -0.37525 | -0.63125 |
| 19 | 83007 | -0.29155 | -0.68496 | -0.56556 | -0.23097 |
| 20 | 83007 | -0.51358 | -0.54333 | -0.36101 | -0.45975 |
| 21 | 98574 | -0.31755 | -0.20929 | -0.39734 | -0.60083 |
| 22 | 98407 | -0.26247 | -0.38107 | -0.39144 | -0.29864 |
| 23 | 98441 | -0.29285 | -0.41956 | -0.35222 | -0.44255 |
| 24 | 98419 | -0.24747 | -0.48824 | -0.23472 | -0.33574 |
| 25 | 98481 | -0.15856 | -0.29127 | -0.25510 | -0.11010 |
|  |  | **** Average Data **** |  |  |  |
| 26 | 44670 | -0.60287 | -0.65666 | -0.56602 | -0.54156 |
| 27 | 55314 | -0.59082 | -0.61508 | -0.62953 | -0.60402 |
| 28 | 72455 | -0.43854 | -0.54492 | -0.54481 | -0.40760 |
| 29 | 83136 | -0.41204 | -0.48868 | -0.41931 | -0.44765 |
| 30 | 98465 | -0.25579 | -0.35789 | -0.32617 | -0.35757 |
|  |  | **** Standard Deviation **** |  |  |  |
| 31 | 44670 | 0.14412 | 0.08580 | 0.19739 | 0.11577 |
| 32 | 55314 | 0.10941 | 0.09820 | 0.16785 | 0.08480 |
| 33 | 72455 | 0.24145 | 0.12327 | 0.20529 | 0.09837 |
| 34 | 83136 | 0.08800 | 0.14503 | 0.08230 | 0.14764 |
| 35 | 98465 | 0.06100 | 0.10843 | 0.07680 | 0.18192 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 27.9
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44340 | -0.47379 | -0.49053 | -0.40950 | -0.53184 |
| 2 | 44348 | -0.39414 | -0.40526 | -0.15900 | -0.30917 |
| 3 | 44347 | -0.42823 | -0.36759 | -0.18867 | -0.17834 |
| 4 | 44328 | -0.37068 | -0.34031 | -0.27241 | -0.34743 |
| 5 | 44342 | -0.30108 | -0.20346 | -0.37656 | -0.35835 |
| 6 | 55480 | -0.38770 | -0.54413 | -0.33109 | -0.74900 |
| 7 | 55504 | -0.30951 | -0.47232 | -0.44951 | -0.46004 |
| 8 | 55475 | -0.41489 | -0.42770 | -0.42311 | -0.45832 |
| 9 | 55437 | -0.49099 | -0.38140 | -0.47094 | -0.54938 |
| 10 | 55451 | -0.42465 | -0.32565 | -0.49030 | -0.44436 |
| 11 | 72144 | -0.35114 | -0.46473 | -0.52390 | -0.47590 |
| 12 | 72119 | -0.35999 | -0.64738 | -0.51977 | -0.41567 |
| 13 | 72137 | -0.39185 | -0.38947 | -0.48218 | -0.37137 |
| 14 | 72105 | -0.24353 | -0.26530 | -0.46439 | -0.31363 |
| 15 | 72105 | -0.32440 | -0.47737 | -0.57393 | -0.27271 |
| 16 | 83284 | -0.29353 | -0.33370 | -0.39860 | -0.46624 |
| 17 | 83273 | -0.09300 | -0.39468 | -0.54478 | -0.39997 |
| 18 | 83240 | -0.40597 | -0.34404 | -0.27140 | -0.29429 |
| 19 | 83056 | -0.24680 | -0.44896 | -0.52228 | -0.18793 |
| 20 | 83079 | -0.29503 | -0.28208 | -0.38966 | -0.34892 |
| 21 | 98939 | -0.19901 | -0.21210 | -0.35303 | -0.45415 |
| 22 | 98931 | -0.25297 | -0.19810 | -0.32520 | -0.25490 |
| 23 | 98939 | -0.20734 | -0.09800 | -0.31065 | -0.21381 |
| 24 | 98962 | -0.06400 | -0.29161 | -0.36595 | -0.21051 |
| 25 | 98912 | -0.07000 | -0.32004 | -0.35728 | -0.32553 |
| | | **** Average Data **** | | | |
| 26 | 44341 | -0.39359 | -0.36143 | -0.28122 | -0.34502 |
| 27 | 55469 | -0.40556 | -0.43024 | -0.43299 | -0.53223 |
| 28 | 72122 | -0.33418 | -0.44885 | -0.51283 | -0.36986 |
| 29 | 83187 | -0.26683 | -0.36070 | -0.42534 | -0.33947 |
| 30 | 98936 | -0.16069 | -0.22389 | -0.34240 | -0.29177 |
| | | **** Standard Deviation **** | | | |
| 31 | 44341 | 0.06470 | 0.10493 | 0.11075 | 0.12657 |
| 32 | 55469 | 0.06510 | 0.08420 | 0.06190 | 0.12816 |
| 33 | 72122 | 0.05640 | 0.13943 | 0.04230 | 0.08086 |
| 34 | 83187 | 0.11332 | 0.06330 | 0.11070 | 0.10739 |
| 35 | 98936 | 0.08360 | 0.08740 | 0.02350 | 0.10182 |

Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 39.52
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44402 | -0.23150 | -0.29976 | -0.14608 | -0.29544 |
| 2 | 44434 | -0.13667 | -0.42859 | -0.09000 | -0.08800 |
| 3 | 44411 | -0.27836 | -0.12372 | -0.18469 | -0.23776 |
| 4 | 44392 | -0.08500 | -0.24557 | -0.15664 | -0.24074 |
| 5 | 44382 | -0.20101 | -0.08900 | -0.22921 | -0.31831 |
| 6 | 55455 | -0.14441 | -0.47277 | -0.18761 | -0.26899 |
| 7 | 55481 | -0.23167 | -0.31757 | -0.25887 | -0.34373 |
| 8 | 55444 | -0.19076 | -0.40305 | -0.32154 | -0.55306 |
| 9 | 55492 | -0.32492 | -0.16642 | -0.24742 | -0.38748 |
| 10 | 55487 | -0.27545 | -0.27574 | -0.16939 | -0.44667 |
| 11 | 72099 | -0.26797 | -0.13714 | -0.21236 | -0.05600 |
| 12 | 72078 | -0.20078 | -0.25801 | -0.29779 | -0.30706 |
| 13 | 72061 | -0.25493 | -0.31536 | -0.29871 | -0.24548 |
| 14 | 72090 | -0.14168 | -0.25732 | -0.32899 | -0.20702 |
| 15 | 72089 | -0.17081 | -0.25807 | -0.25544 | -0.14005 |
| 16 | 83297 | -0.10453 | -0.23441 | -0.23578 | -0.24469 |
| 17 | 83342 | -0.17524 | -0.13216 | -0.18995 | -0.25482 |
| 18 | 83337 | -0.12619 | -0.34663 | -0.23622 | -0.14604 |
| 19 | 83286 | -0.25206 | -0.25482 | -0.29591 | -0.32261 |
| 20 | 83249 | -0.15109 | -0.27283 | -0.32497 | -0.35443 |
| 21 | 98834 | -0.03600 | -0.21279 | -0.23936 | -0.15089 |
| 22 | 98878 | -0.03100 | -0.12719 | -0.17926 | -0.08700 |
| 23 | 98809 | 0.00763 | -0.16398 | -0.03300 | -0.13692 |
| 24 | 98825 | -0.11480 | -0.11800 | -0.15621 | -0.13315 |
| 25 | 98783 | -0.13527 | -0.14960 | -0.14568 | -0.18349 |
| | | **** | Average Data | **** | |
| 26 | 44404 | -0.18644 | -0.23738 | -0.16324 | -0.23613 |
| 27 | 55472 | -0.23344 | -0.32711 | -0.23696 | -0.39999 |
| 28 | 72083 | -0.20723 | -0.24518 | -0.27865 | -0.19117 |
| 29 | 83302 | -0.16183 | -0.24818 | -0.25657 | -0.26452 |
| 30 | 98826 | -0.06200 | -0.15431 | -0.15064 | -0.13830 |
| | | **** | Standard Deviation | | **** |
| 31 | 44404 | 0.07670 | 0.13767 | 0.04750 | 0.08920 |
| 32 | 55472 | 0.07000 | 0.11738 | 0.06050 | 0.10723 |
| 33 | 72083 | 0.05390 | 0.06510 | 0.04520 | 0.09650 |
| 34 | 83302 | 0.05690 | 0.07730 | 0.05200 | 0.08000 |
| 35 | 98826 | 0.06030 | 0.03730 | 0.07550 | 0.03430 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 51.14
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44534 | -0.14369 | -0.22799 | -0.15159 | -0.39507 |
| 2 | 44524 | 0.06690 | -0.17805 | -0.07700 | -0.21716 |
| 3 | 44549 | -0.09400 | -0.03300 | 0.04507 | -0.08371 |
| 4 | 44518 | -0.06500 | 0.00004 | -0.04600 | -0.28844 |
| 5 | 44536 | -0.03000 | -0.13668 | -0.22583 | -0.13103 |
| 6 | 55682 | -0.03900 | -0.15753 | -0.04000 | -0.02000 |
| 7 | 55672 | -0.00670 | -0.10556 | -0.16705 | -0.16640 |
| 8 | 55690 | 0.07480 | -0.13633 | -0.16601 | -0.09600 |
| 9 | 55662 | -0.13585 | -0.07400 | -0.11431 | -0.24084 |
| 10 | 55665 | -0.08300 | 0.00986 | -0.10687 | -0.11782 |
| 11 | 72121 | -0.04400 | -0.02000 | -0.05400 | -0.19231 |
| 12 | 72086 | -0.05200 | -0.08400 | -0.05200 | -0.11283 |
| 13 | 72086 | -0.23727 | 0.04380 | -0.01300 | -0.06300 |
| 14 | 72103 | 0.01380 | -0.14040 | 0.02270 | 0.06640 |
| 15 | 72080 | -0.02974 | -0.05628 | -0.10585 | -0.02400 |
| 16 | 83212 | 0.03010 | 0.09654 | -0.03900 | -0.03200 |
| 17 | 83152 | -0.09000 | -0.07000 | -0.01300 | -0.07500 |
| 18 | 83139 | -0.02400 | -0.07500 | -0.02800 | -0.01800 |
| 19 | 83144 | 0.04910 | -0.07400 | -0.02900 | 0.04870 |
| 20 | 83105 | -0.13173 | -0.08500 | -0.12095 | 0.00367 |
| 21 | 99118 | 0.04470 | 0.05330 | -0.02800 | -0.06200 |
| 22 | 99115 | 0.13942 | -0.00800 | -0.00820 | 0.11294 |
| 23 | 99089 | 0.06120 | 0.07249 | 0.05480 | 0.14907 |
| 24 | 99056 | -0.03200 | -0.02900 | -0.01200 | 0.04620 |
| 25 | 99061 | 0.07850 | -0.01900 | -0.04500 | 0.08290 |
| | | **** Average Data **** | | | |
| 26 | 44532 | -0.05500 | -0.11513 | -0.09100 | -0.22308 |
| 27 | 55674 | -0.03800 | -0.09300 | -0.11894 | -0.13021 |
| 28 | 72095 | -0.06000 | -0.05100 | -0.04033 | -0.06500 |
| 29 | 83151 | -0.03500 | -0.04145 | -0.04600 | -0.01452 |
| 30 | 99088 | 0.05830 | 0.01390 | -0.00770 | 0.06580 |
| | | **** Standard Deviation **** | | | |
| 31 | 44532 | 0.07850 | 0.09640 | 0.10317 | 0.12411 |
| 32 | 55674 | 0.07930 | 0.06560 | 0.05210 | 0.07870 |
| 33 | 72095 | 0.09690 | 0.06900 | 0.04830 | 0.09690 |
| 34 | 83151 | 0.07860 | 0.07670 | 0.04240 | 0.04580 |
| 35 | 99088 | 0.06170 | 0.04570 | 0.03780 | 0.08110 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 62.76
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44371 | -0.07600 | -0.11575 | 0.20564 | 0.20956 |
| 2 | 44338 | 0.08910 | -0.05700 | 0.15701 | 0.07120 |
| 3 | 44299 | -0.03600 | 0.08980 | 0.12927 | 0.12497 |
| 4 | 44328 | 0.14232 | 0.00713 | 0.00929 | 0.03230 |
| 5 | 44304 | -0.11298 | 0.21731 | 0.29194 | 0.31162 |
| 6 | 55566 | -0.06100 | -0.05800 | -0.01000 | 0.11832 |
| 7 | 55540 | 0.01590 | -0.06100 | -0.13329 | 0.00920 |
| 8 | 55556 | 0.11444 | -0.05000 | -0.07600 | -0.04900 |
| 9 | 55530 | -0.10631 | -0.08700 | 0.02620 | -0.10757 |
| 10 | 55579 | 0.02280 | -0.04800 | -0.05100 | -0.16271 |
| 11 | 72124 | -0.10686 | -0.14596 | -0.03244 | -0.23173 |
| 12 | 72114 | -0.03700 | -0.09700 | 0.02940 | -0.09900 |
| 13 | 72094 | 0.09061 | -0.17706 | 0.02070 | -0.04500 |
| 14 | 72115 | 0.03040 | -0.19295 | 0.00367 | 0.04710 |
| 15 | 72071 | 0.00358 | -0.20961 | -0.08700 | -0.18079 |
| 16 | 83260 | -0.00430 | -0.14229 | -0.06200 | -0.02800 |
| 17 | 83262 | -0.06500 | -0.06400 | -0.01900 | 0.09000 |
| 18 | 83283 | 0.06180 | -0.01113 | -0.00350 | -0.14660 |
| 19 | 83268 | 0.11591 | -0.02900 | 0.00651 | -0.06300 |
| 20 | 83284 | 0.03980 | -0.05200 | 0.03860 | -0.10304 |
| 21 | 98805 | 0.05336 | 0.03080 | -0.08400 | 0.10548 |
| 22 | 98853 | 0.15123 | 0.03750 | 0.01970 | 0.11671 |
| 23 | 98848 | 0.01430 | -0.02959 | 0.05060 | 0.11465 |
| 24 | 98828 | 0.12617 | 0.03270 | -0.09800 | 0.10591 |
| 25 | 98806 | 0.10598 | 0.02560 | -0.00540 | -0.07100 |
| | | **** Average Data **** | | | |
| 26 | 44328 | 0.00137 | 0.02840 | 0.15863 | 0.14995 |
| 27 | 55554 | -0.00290 | -0.06300 | -0.05100 | -0.03800 |
| 28 | 72103 | -0.00390 | -0.16449 | -0.01300 | -0.10205 |
| 29 | 83271 | 0.02970 | -0.05986 | -0.00790 | -0.05000 |
| 30 | 98828 | 0.09021 | 0.01940 | -0.02300 | 0.07440 |
| | | **** Standard Deviation **** | | | |
| 31 | 44328 | 0.10944 | 0.13102 | 0.10389 | 0.11228 |
| 32 | 55554 | 0.08480 | 0.01300 | 0.05990 | 0.10863 |
| 33 | 72103 | 0.07420 | 0.04420 | 0.04750 | 0.11004 |
| 34 | 83271 | 0.06820 | 0.05030 | 0.03670 | 0.09020 |
| 35 | 98828 | 0.05560 | 0.02790 | 0.06470 | 0.08120 |

# APPENDIX B

## Orifice Flowmeter Performance for a Header H342-100/0-1 with a 19-Tube Tube Bundle

## Meters in the Outlet Pipe #1 with the Outlet #1 Opened and the Outlet #2 Closed

Tube Bundle Entrance Location, Z= 4.26D
Tube Bundle Exit Location, Z= 6.2D
Water Temperature =21.5 °C
Gage Pressure = 138 kPa (20 PSI)
Water Density = 997.88 kg/m$^3$
Water Kinematic Viscosity = 9.71958*10$^{-7}$
Meter Tube Diameter, D= 52.5 mm (2.07")

## Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D and Beta = 0.3995169

Orifice Plate Axial Position Z/D= 8.92, C/D= 2.72
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100 At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22520 | -0.47277 | -0.36004 | -0.47485 | -0.48338 |
| 2 | 22524 | -0.43597 | -0.45856 | -0.44662 | -0.45172 |
| 3 | 22532 | -0.38881 | -0.38556 | -0.37857 | -0.52933 |
| 4 | 22515 | -0.45036 | -0.41585 | -0.44744 | -0.47696 |
| 5 | 22516 | -0.37589 | -0.39867 | -0.41851 | -0.46351 |
| 6 | 28945 | -0.52198 | -0.47407 | -0.49958 | -0.56505 |
| 7 | 28932 | -0.49581 | -0.49881 | -0.52306 | -0.57226 |
| 8 | 28940 | -0.48166 | -0.44628 | -0.50080 | -0.52812 |
| 9 | 28926 | -0.55529 | -0.53158 | -0.55653 | -0.59134 |
| 10 | 28937 | -0.45931 | -0.43467 | -0.52582 | -0.51390 |
| 11 | 36191 | -0.53631 | -0.55319 | -0.59383 | -0.58785 |
| 12 | 36187 | -0.54042 | -0.53551 | -0.53519 | -0.57743 |
| 13 | 36167 | -0.59094 | -0.52365 | -0.60775 | -0.60220 |
| 14 | 36176 | -0.57841 | -0.49286 | -0.57920 | -0.61406 |
| 15 | 36171 | -0.56378 | -0.51613 | -0.59445 | -0.62198 |
| 16 | 44380 | -0.60810 | -0.58338 | -0.62173 | -0.61535 |
| 17 | 44406 | -0.56437 | -0.56130 | -0.56354 | -0.60369 |
| 18 | 44399 | -0.57558 | -0.55709 | -0.56423 | -0.60369 |
| 19 | 44404 | -0.55113 | -0.52144 | -0.55233 | -0.61532 |
| 20 | 44413 | -0.55698 | -0.54094 | -0.57060 | -0.56249 |
| 21 | 55481 | -0.55002 | -0.55360 | -0.55132 | -0.58678 |
| 22 | 55443 | -0.62228 | -0.56839 | -0.62517 | -0.60476 |
| 23 | 55458 | -0.58810 | -0.56182 | -0.62273 | -0.64252 |
| 24 | 55504 | -0.54548 | -0.54208 | -0.54478 | -0.58888 |
| 25 | 55474 | -0.54791 | -0.51766 | -0.57632 | -0.58991 |
| | | **** Average Data **** | | | |
| 26 | 22521 | -0.42477 | -0.40374 | -0.43319 | -0.48098 |
| 27 | 28936 | -0.50281 | -0.47708 | -0.52116 | -0.55413 |
| 28 | 36178 | -0.56197 | -0.52427 | -0.58208 | -0.60072 |
| 29 | 44400 | -0.57123 | -0.55283 | -0.57448 | -0.60010 |
| 30 | 55472 | -0.57075 | -0.54872 | -0.58406 | -0.60256 |
| | | **** Standard Deviation **** | | | |
| 31 | 22521 | 0.04110 | 0.03680 | 0.03640 | 0.02970 |
| 32 | 28936 | 0.03710 | 0.03930 | 0.02310 | 0.03210 |
| 33 | 36178 | 0.02350 | 0.02250 | 0.02801 | 0.01820 |
| 34 | 44400 | 0.02240 | 0.02310 | 0.02710 | 0.02170 |
| 35 | 55472 | 0.03350 | 0.01980 | 0.03800 | 0.02330 |

## Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D and Beta = 0.3995169

Orifice Plate Axial Position Z/D= 14.73, C/D= 8.53
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

$\Delta C_d[\%]$, $(C_d/C_{d,s}-1)*100$
At Pressure Tap Positions

| No. | Re | 0° | 90° | 180° | 270° |
|---|---|---|---|---|---|
| 1 | 22198 | -0.11898 | -0.05561 | -0.02600 | -0.10959 |
| 2 | 22155 | -0.09800 | -0.10804 | -0.01100 | -0.08000 |
| 3 | 22167 | -0.08500 | -0.04000 | -0.00210 | -0.06700 |
| 4 | 22179 | -0.06200 | 0.06060 | 0.01220 | -0.13233 |
| 5 | 22189 | -0.02200 | -0.10097 | -0.06200 | -0.09400 |
| 6 | 28981 | -0.13642 | -0.09900 | -0.08500 | -0.18313 |
| 7 | 28980 | -0.09500 | -0.04900 | -0.02800 | -0.11144 |
| 8 | 28967 | -0.16202 | -0.11601 | -0.15569 | -0.15532 |
| 9 | 28978 | -0.14196 | -0.07900 | -0.05400 | -0.16425 |
| 10 | 28972 | -0.09400 | -0.03400 | -0.06700 | -0.12727 |
| 11 | 36120 | -0.14603 | -0.04700 | -0.07500 | -0.16538 |
| 12 | 36120 | -0.12412 | -0.10827 | -0.12986 | -0.18512 |
| 13 | 36105 | -0.17797 | -0.11180 | -0.13684 | -0.21677 |
| 14 | 36087 | -0.21471 | -0.17467 | -0.16031 | -0.23086 |
| 15 | 36103 | -0.18908 | -0.13313 | -0.06800 | -0.19491 |
| 16 | 44555 | -0.22899 | -0.18952 | -0.18746 | -0.23435 |
| 17 | 44528 | -0.24810 | -0.17601 | -0.19762 | -0.21763 |
| 18 | 44542 | -0.18018 | -0.12516 | -0.14451 | -0.18243 |
| 19 | 44532 | -0.22296 | -0.17862 | -0.18281 | -0.23382 |
| 20 | 44510 | -0.27807 | -0.25913 | -0.24624 | -0.27145 |
| 21 | 55575 | -0.26756 | -0.23005 | -0.20491 | -0.26935 |
| 22 | 55589 | -0.25472 | -0.18137 | -0.16195 | -0.21095 |
| 23 | 55608 | -0.20364 | -0.16958 | -0.13149 | -0.19908 |
| 24 | 55573 | -0.25055 | -0.21035 | -0.20308 | -0.25756 |
| 25 | 55587 | -0.23254 | -0.22305 | -0.20996 | -0.24143 |
| | | **** | Average Data | **** | |
| 26 | 22178 | -0.07700 | -0.04900 | -0.01794 | -0.09700 |
| 27 | 28976 | -0.12595 | -0.07500 | -0.07800 | -0.14828 |
| 28 | 36107 | -0.17038 | -0.11504 | -0.11408 | -0.19861 |
| 29 | 44533 | -0.23166 | -0.18569 | -0.19173 | -0.22792 |
| 30 | 55586 | -0.24180 | -0.20289 | -0.18228 | -0.23568 |
| | | **** | Standard Deviation | **** | |
| 31 | 22178 | 0.03700 | 0.06770 | 0.02850 | 0.02580 |
| 32 | 28976 | 0.03010 | 0.03400 | 0.04820 | 0.02880 |
| 33 | 36107 | 0.03550 | 0.04500 | 0.04030 | 0.02560 |
| 34 | 44533 | 0.03580 | 0.04786 | 0.03640 | 0.03210 |
| 35 | 55586 | 0.02460 | 0.02620 | 0.03415 | 0.02980 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 20.54, C/D= 14.34
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

$\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$
At Pressure Tap Positions

| No. | Re | 0° | 90° | 180° | 270° |
|---|---|---|---|---|---|
| 1 | 22377 | -0.03200 | 0.00685 | 0.05090 | -0.02000 |
| 2 | 22380 | 0.09450 | 0.04200 | 0.09450 | 0.04370 |
| 3 | 22396 | 0.04930 | 0.07130 | 0.06300 | 0.00558 |
| 4 | 22381 | -0.00570 | 0.05760 | 0.10638 | 0.05720 |
| 5 | 22399 | 0.01490 | 0.03200 | 0.07100 | 0.02120 |
| 6 | 28940 | -0.05900 | 0.02510 | 0.03030 | 0.03580 |
| 7 | 28943 | -0.03400 | 0.03840 | 0.04190 | 0.01300 |
| 8 | 28938 | 0.00725 | 0.05210 | 0.05770 | -0.03600 |
| 9 | 28950 | 0.02735 | 0.09290 | 0.06880 | 0.05414 |
| 10 | 28941 | 0.05930 | 0.06500 | 0.08290 | -0.01489 |
| 11 | 36179 | -0.05100 | -0.01900 | -0.02100 | -0.03400 |
| 12 | 36161 | -0.02500 | -0.00380 | -0.00190 | -0.04900 |
| 13 | 36164 | -0.01300 | 0.01670 | 0.02060 | 0.06540 |
| 14 | 36154 | -0.07300 | 0.02890 | 0.03700 | -0.02400 |
| 15 | 36163 | 0.02237 | 0.05080 | 0.04790 | 0.00072 |
| 16 | 44477 | -0.07000 | -0.05500 | -0.02064 | -0.04100 |
| 17 | 44470 | -0.01652 | 0.00103 | 0.02100 | -0.06300 |
| 18 | 44461 | -0.09623 | -0.04600 | -0.02400 | -0.07200 |
| 19 | 44457 | -0.05000 | -0.01100 | 0.00311 | -0.09069 |
| 20 | 44472 | -0.03388 | -0.00340 | 0.00180 | -0.03500 |
| 21 | 55514 | -0.06934 | -0.07200 | -0.03700 | -0.06900 |
| 22 | 55532 | -0.03800 | -0.07800 | -0.06012 | -0.05600 |
| 23 | 55513 | -0.07900 | -0.03600 | -0.02296 | -0.09600 |
| 24 | 55536 | -0.01000 | -0.03300 | -0.01700 | -0.07600 |
| 25 | 55528 | -0.01800 | -0.02200 | -0.03100 | -0.01800 |
| | | **** | Average Data | **** | |
| 26 | 22386 | 0.02410 | 0.04220 | 0.07710 | 0.02150 |
| 27 | 28942 | 0.00007 | 0.05490 | 0.05630 | 0.01040 |
| 28 | 36164 | -0.02800 | 0.01460 | 0.01650 | -0.00810 |
| 29 | 44468 | -0.05300 | -0.02300 | -0.00370 | -0.06000 |
| 30 | 55525 | -0.04300 | -0.04800 | -0.03400 | -0.06309 |
| | | **** | Standard Deviation | **** | |
| 31 | 22386 | 0.04940 | 0.02460 | 0.02290 | 0.03070 |
| 32 | 28942 | 0.04740 | 0.02610 | 0.02090 | 0.03650 |
| 33 | 36164 | 0.03650 | 0.02760 | 0.02830 | 0.04490 |
| 34 | 44468 | 0.03100 | 0.02570 | 0.01860 | 0.02280 |
| 35 | 55525 | 0.03040 | 0.02512 | 0.01660 | 0.02890 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 26.35, C/D= 20.15
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], | $(C_d/C_{d,s}-1)*100$ | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22395 | 0.03920 | 0.06160 | 0.11693 | 0.03870 |
| 2 | 22375 | 0.07400 | 0.08960 | 0.17824 | 0.05250 |
| 3 | 22381 | 0.08800 | 0.13846 | 0.13485 | 0.09480 |
| 4 | 22373 | 0.11217 | 0.10208 | 0.14194 | 0.08160 |
| 5 | 22374 | 0.05850 | 0.11660 | 0.15285 | 0.08540 |
| 6 | 28892 | 0.07570 | 0.13241 | 0.13385 | 0.08280 |
| 7 | 28879 | 0.10706 | 0.11917 | 0.17782 | 0.09570 |
| 8 | 28855 | -0.01400 | 0.06440 | 0.11264 | 0.01170 |
| 9 | 28873 | 0.01310 | 0.08310 | 0.18740 | 0.02430 |
| 10 | 28856 | 0.03930 | 0.10274 | 0.14661 | 0.04280 |
| 11 | 36211 | 0.03070 | 0.07140 | 0.12400 | 0.01460 |
| 12 | 36209 | -0.02000 | 0.07910 | 0.11736 | 0.00181 |
| 13 | 36197 | 0.01840 | 0.11209 | 0.11281 | -0.00300 |
| 14 | 36224 | 0.06310 | 0.12611 | 0.14595 | 0.06110 |
| 15 | 36235 | 0.08120 | 0.07570 | 0.15473 | 0.04350 |
| 16 | 44452 | -0.02900 | 0.02929 | 0.05140 | 0.00964 |
| 17 | 44474 | 0.05710 | 0.04940 | 0.10638 | 0.03890 |
| 18 | 44453 | 0.01010 | -0.00360 | 0.05920 | -0.02800 |
| 19 | 44462 | 0.01870 | 0.06490 | 0.10118 | 0.00400 |
| 20 | 44470 | 0.03450 | 0.08510 | 0.09694 | -0.00450 |
| 21 | 55521 | 0.02150 | -0.01300 | 0.03520 | -0.02000 |
| 22 | 55538 | 0.04850 | 0.04209 | 0.04340 | 0.01480 |
| 23 | 55531 | -0.00840 | 0.03030 | 0.04690 | -0.03283 |
| 24 | 55552 | 0.01320 | 0.00745 | 0.06420 | 0.00606 |
| 25 | 55537 | 0.03750 | 0.06520 | 0.08260 | 0.04390 |
| | | **** | Average Data | **** | |
| 26 | 22380 | 0.07440 | 0.10165 | 0.14495 | 0.07060 |
| 27 | 28871 | 0.04434 | 0.10036 | 0.15166 | 0.05140 |
| 28 | 36215 | 0.03470 | 0.09290 | 0.13097 | 0.02340 |
| 29 | 44462 | 0.01830 | 0.04500 | 0.08300 | 0.00410 |
| 30 | 55536 | 0.02250 | 0.02630 | 0.05447 | 0.00237 |
| | | **** | Standard Deviation | **** | |
| 31 | 22380 | 0.02700 | 0.02890 | 0.02280 | 0.02390 |
| 32 | 28871 | 0.04796 | 0.02710 | 0.03090 | 0.03630 |
| 33 | 36215 | 0.03940 | 0.02460 | 0.01820 | 0.02770 |
| 34 | 44462 | 0.03180 | 0.03390 | 0.02550 | 0.02399 |
| 35 | 55536 | 0.02200 | 0.03040 | 0.01890 | 0.03010 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 37.97, C/D= 31.77
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 22228 | 0.07320 | 0.13435 | 0.12586 | -0.01900 |
| 2 | 22218 | 0.01500 | 0.10599 | 0.04600 | -0.06900 |
| 3 | 22238 | 0.06090 | 0.06280 | 0.17154 | 0.03330 |
| 4 | 22223 | 0.09800 | 0.07280 | 0.13336 | 0.00696 |
| 5 | 22211 | 0.05350 | 0.02080 | 0.10216 | 0.10185 |
| 6 | 28884 | 0.03210 | 0.13174 | 0.16409 | -0.01757 |
| 7 | 28881 | 0.02440 | 0.09118 | 0.15124 | 0.06050 |
| 8 | 28855 | 0.05540 | 0.04160 | 0.08280 | 0.03350 |
| 9 | 28867 | -0.00710 | 0.05140 | 0.02690 | -0.05000 |
| 10 | 28865 | -0.01000 | -0.00092 | -0.00720 | -0.06600 |
| 11 | 36123 | 0.03045 | -0.02400 | 0.06380 | -0.02568 |
| 12 | 36134 | 0.00850 | 0.03340 | 0.03700 | 0.01650 |
| 13 | 36118 | -0.00300 | 0.07830 | 0.05060 | 0.02890 |
| 14 | 36108 | -0.01500 | 0.01710 | 0.01970 | -0.06969 |
| 15 | 36096 | -0.02400 | -0.05600 | 0.02970 | -0.04500 |
| 16 | 44546 | 0.00197 | 0.07988 | 0.09290 | 0.01590 |
| 17 | 44542 | -0.00860 | 0.02063 | 0.05830 | -0.01200 |
| 18 | 44546 | 0.04170 | 0.06970 | 0.08890 | -0.02400 |
| 19 | 44508 | -0.02063 | -0.00460 | 0.01270 | -0.05420 |
| 20 | 44522 | 0.02330 | 0.08540 | 0.05890 | 0.06310 |
| 21 | 55666 | 0.04280 | 0.07110 | 0.07420 | -0.00720 |
| 22 | 55653 | -0.00300 | -0.02900 | 0.03600 | -0.03900 |
| 23 | 55645 | -0.02100 | -0.00710 | 0.04160 | -0.05000 |
| 24 | 55689 | 0.02210 | 0.04230 | 0.06670 | 0.03630 |
| 25 | 55661 | -0.01200 | 0.02800 | 0.04480 | 0.00207 |
| | | **** Average Data **** | | | |
| 26 | 22224 | 0.06030 | 0.07934 | 0.11598 | 0.01080 |
| 27 | 28871 | 0.01710 | 0.06300 | 0.08360 | -0.00800 |
| 28 | 36116 | -0.00064 | 0.00973 | 0.04040 | -0.01900 |
| 29 | 44533 | 0.00754 | 0.05020 | 0.06240 | -0.00240 |
| 30 | 55663 | 0.00578 | 0.02120 | 0.05280 | -0.01400 |
| | | **** Standard Deviation **** | | | |
| 31 | 22224 | 0.03060 | 0.04320 | 0.04580 | 0.06337 |
| 32 | 28871 | 0.03030 | 0.05030 | 0.07490 | 0.05400 |
| 33 | 36116 | 0.02110 | 0.05180 | 0.01720 | 0.04120 |
| 34 | 44533 | 0.02490 | 0.03980 | 0.03190 | 0.04430 |
| 35 | 55663 | 0.02610 | 0.03980 | 0.01640 | 0.03710 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.3995169
Orifice Plate Axial Position Z/D= 55.44, C/D= 49.2
Orifice Plate: Hole Diameter, d= 21 mm (0.827")

$\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$
At Pressure Tap Positions

| No. | Re | 0° | 90° | 180° | 270° |
|---|---|---|---|---|---|
| 1 | 22394 | 0.09020 | 0.10947 | 0.09020 | -0.04300 |
| 2 | 22376 | 0.03520 | 0.02380 | 0.07000 | 0.02340 |
| 3 | 22383 | 0.01960 | 0.08130 | 0.10086 | -0.06700 |
| 4 | 22386 | 0.06310 | -0.05500 | -0.02000 | 0.07000 |
| 5 | 22385 | 0.03190 | 0.01000 | 0.00816 | -0.00420 |
| 6 | 28945 | 0.00981 | 0.00452 | 0.02090 | -0.01000 |
| 7 | 28928 | -0.01169 | -0.02100 | -0.03800 | -0.03000 |
| 8 | 28948 | 0.02840 | 0.02210 | 0.01820 | -0.03700 |
| 9 | 28910 | -0.01600 | 0.02450 | -0.01000 | -0.05000 |
| 10 | 28937 | 0.00089 | 0.01120 | 0.04280 | -0.08000 |
| 11 | 36039 | 0.01500 | 0.02070 | 0.03950 | 0.00607 |
| 12 | 36008 | -0.01608 | -0.08500 | -0.04700 | -0.09800 |
| 13 | 36019 | -0.02700 | 0.00990 | -0.00860 | -0.07000 |
| 14 | 36006 | -0.03446 | -0.03000 | -0.04291 | -0.05700 |
| 15 | 36024 | -0.00560 | 0.05500 | -0.00830 | -0.03800 |
| 16 | 44495 | 0.02250 | 0.04980 | 0.01271 | -0.03400 |
| 17 | 44491 | 0.00095 | -0.05300 | -0.03800 | -0.08900 |
| 18 | 44494 | -0.00770 | -0.01000 | -0.00870 | -0.07500 |
| 19 | 44458 | -0.01600 | -0.09500 | -0.11156 | -0.09600 |
| 20 | 44491 | -0.02500 | -0.06100 | -0.04600 | -0.09300 |
| 21 | 55809 | 0.01890 | 0.01550 | 0.01540 | -0.03500 |
| 22 | 55774 | -0.00720 | -0.03500 | -0.02000 | -0.07000 |
| 23 | 55786 | -0.01300 | -0.03000 | -0.03400 | -0.04200 |
| 24 | 55767 | -0.00063 | -0.09400 | -0.06100 | -0.09300 |
| 25 | 55773 | -0.02400 | 0.00537 | -0.02200 | -0.07500 |
| | | **** Average Data **** | | | |
| 26 | 22385 | 0.04800 | 0.03410 | 0.04790 | -0.00400 |
| 27 | 28934 | 0.00217 | 0.00817 | 0.00473 | -0.04300 |
| 28 | 36019 | -0.01400 | -0.00580 | -0.01400 | -0.05100 |
| 29 | 44486 | -0.00400 | -0.03400 | -0.03818 | -0.07700 |
| 30 | 55782 | -0.00520 | -0.02800 | -0.02400 | -0.06500 |
| | | **** Standard Deviation **** | | | |
| 31 | 22385 | 0.02840 | 0.06420 | 0.05630 | 0.05450 |
| 32 | 28934 | 0.01770 | 0.01840 | 0.03280 | 0.02950 |
| 33 | 36019 | 0.01960 | 0.05390 | 0.03471 | 0.03860 |
| 34 | 44486 | 0.01700 | 0.05560 | 0.04600 | 0.02540 |
| 35 | 55782 | 0.01581 | 0.04294 | 0.02734 | 0.02500 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 8.92, C/D= 2.72
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100<br>At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36230 | -1.46115 | -1.36205 | -1.48594 | -1.64825 |
| 2 | 36236 | -1.45765 | -1.55325 | -1.54058 | -1.65583 |
| 3 | 36266 | -1.44924 | -1.44226 | -1.52059 | -1.57845 |
| 4 | 36235 | -1.56522 | -1.42818 | -1.53340 | -1.59095 |
| 5 | 36220 | -1.43354 | -1.52412 | -1.51329 | -1.74641 |
| 6 | 44728 | -1.60727 | -1.46109 | -1.55236 | -1.50938 |
| 7 | 44668 | -1.65199 | -1.55347 | -1.68652 | -1.69237 |
| 8 | 44659 | -1.72665 | -1.63641 | -1.69809 | -1.76820 |
| 9 | 44668 | -1.57845 | -1.60142 | -1.74024 | -1.70463 |
| 10 | 44673 | -1.69851 | -1.52583 | -1.63922 | -1.75369 |
| 11 | 56137 | -1.68896 | -1.68546 | -1.70104 | -1.60525 |
| 12 | 56137 | -1.70322 | -1.61271 | -1.71093 | -1.65150 |
| 13 | 56128 | -1.76966 | -1.58440 | -1.72586 | -1.63741 |
| 14 | 56125 | -1.69680 | -1.56022 | -1.65366 | -1.67238 |
| 15 | 56132 | -1.67946 | -1.53722 | -1.70739 | -1.69273 |
| 16 | 72459 | -1.73642 | -1.54698 | -1.66218 | -1.69749 |
| 17 | 72489 | -1.68166 | -1.66249 | -1.68651 | -1.75608 |
| 18 | 72472 | -1.67499 | -1.62599 | -1.66029 | -1.67705 |
| 19 | 72484 | -1.67805 | -1.58868 | -1.63992 | -1.64136 |
| 20 | 72482 | -1.63838 | -1.70123 | -1.67639 | -1.73892 |
| 21 | 83300 | -1.62505 | -1.53745 | -1.60124 | -1.64513 |
| 22 | 83278 | -1.69956 | -1.68152 | -1.62485 | -1.72761 |
| 23 | 83290 | -1.65782 | -1.56098 | -1.60461 | -1.69760 |
| 24 | 83273 | -1.64925 | -1.60805 | -1.66286 | -1.70716 |
| 25 | 83277 | -1.62446 | -1.58997 | -1.67004 | -1.72917 |
| | | **** Average Data **** | | | |
| 26 | 36237 | -1.47336 | -1.46198 | -1.51877 | -1.64398 |
| 27 | 44679 | -1.65258 | -1.55564 | -1.66329 | -1.68566 |
| 28 | 56132 | -1.70763 | -1.59600 | -1.69978 | -1.65185 |
| 29 | 72477 | -1.68191 | -1.62508 | -1.66506 | -1.70210 |
| 30 | 83284 | -1.65123 | -1.59550 | -1.63272 | -1.70136 |
| | | **** Standard Deviation **** | | | |
| 31 | 36237 | 0.05240 | 0.07690 | 0.02130 | 0.06640 |
| 32 | 44679 | 0.06130 | 0.06750 | 0.07120 | 0.10312 |
| 33 | 56132 | 0.03580 | 0.05740 | 0.02740 | 0.03340 |
| 34 | 72477 | 0.03400 | 0.06060 | 0.01770 | 0.04640 |
| 35 | 83284 | 0.03070 | 0.05500 | 0.03210 | 0.03410 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 14.73, C/D= 8.53
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], ($C_d/C_{d,s}$-1)*100 At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36173 | -0.32167 | -0.33639 | -0.19509 | -0.39118 |
| 2 | 36191 | -0.27566 | -0.27777 | -0.11957 | -0.35649 |
| 3 | 36180 | -0.22903 | -0.51321 | -0.12749 | -0.38240 |
| 4 | 36180 | -0.18279 | -0.31157 | -0.09500 | -0.23941 |
| 5 | 36182 | -0.25055 | -0.51584 | -0.09700 | -0.29694 |
| 6 | 44446 | -0.37379 | -0.39891 | -0.33567 | -0.50871 |
| 7 | 44445 | -0.34306 | -0.61848 | -0.28243 | -0.41215 |
| 8 | 44486 | -0.31619 | -0.44522 | -0.23116 | -0.30317 |
| 9 | 44440 | -0.44427 | -0.35379 | -0.27052 | -0.27229 |
| 10 | 44458 | -0.29701 | -0.50333 | -0.22096 | -0.22140 |
| 11 | 55678 | -0.36723 | -0.36575 | -0.31482 | -0.39919 |
| 12 | 55679 | -0.35540 | -0.33507 | -0.39826 | -0.48674 |
| 13 | 55675 | -0.33389 | -0.45599 | -0.35880 | -0.40337 |
| 14 | 55663 | -0.37549 | -0.41411 | -0.31109 | -0.39276 |
| 15 | 55638 | -0.45691 | -0.38344 | -0.39454 | -0.55426 |
| 16 | 72205 | -0.43647 | -0.47152 | -0.38206 | -0.43908 |
| 17 | 72230 | -0.42383 | -0.48842 | -0.36762 | -0.43726 |
| 18 | 72209 | -0.42884 | -0.48321 | -0.39088 | -0.40865 |
| 19 | 72214 | -0.44778 | -0.45830 | -0.37699 | -0.45490 |
| 20 | 72199 | -0.45921 | -0.42719 | -0.40776 | -0.44834 |
| 21 | 83224 | -0.48859 | -0.57900 | -0.41529 | -0.40224 |
| 22 | 83214 | -0.42647 | -0.56120 | -0.37222 | -0.39467 |
| 23 | 83119 | -0.45768 | -0.53625 | -0.43373 | -0.46376 |
| 24 | 83043 | -0.46184 | -0.55294 | -0.44441 | -0.44878 |
| 25 | 83047 | -0.42147 | -0.51471 | -0.40337 | -0.41566 |
| | | **** Average Data **** | | | |
| 26 | 36181 | -0.25193 | -0.39096 | -0.12679 | -0.33328 |
| 27 | 44455 | -0.35487 | -0.46395 | -0.26815 | -0.34354 |
| 28 | 55667 | -0.37779 | -0.39087 | -0.35550 | -0.44726 |
| 29 | 72212 | -0.43923 | -0.46574 | -0.38507 | -0.43764 |
| 30 | 83129 | -0.45122 | -0.54881 | -0.41380 | -0.42502 |
| | | **** Standard Deviation **** | | | |
| 31 | 36181 | 0.05180 | 0.11468 | 0.04060 | 0.06410 |
| 32 | 44455 | 0.05750 | 0.10266 | 0.04550 | 0.11567 |
| 33 | 55667 | 0.04670 | 0.04630 | 0.04170 | 0.07090 |
| 34 | 72212 | 0.01425 | 0.02460 | 0.01510 | 0.01770 |
| 35 | 83129 | 0.02790 | 0.02530 | 0.02760 | 0.02940 |

Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D and Beta = 0.5990338

Orifice Plate Axial Position Z/D= 20.54, C/D= 14.34

Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36144 | -0.03200 | 0.14888 | 0.14570 | 0.00655 |
| 2 | 36169 | 0.04648 | 0.17369 | 0.19766 | 0.13223 |
| 3 | 36150 | 0.09580 | 0.14922 | 0.22798 | 0.07140 |
| 4 | 36123 | 0.14645 | -0.05500 | 0.16031 | 0.10683 |
| 5 | 36135 | 0.02540 | 0.03860 | 0.15153 | 0.15893 |
| 6 | 44555 | 0.03732 | 0.05830 | 0.13052 | 0.10567 |
| 7 | 44550 | 0.01310 | 0.13053 | 0.11988 | 0.07650 |
| 8 | 44562 | 0.13493 | 0.15170 | 0.11628 | 0.12031 |
| 9 | 44551 | 0.07140 | 0.19700 | 0.12255 | 0.09510 |
| 10 | 44545 | 0.08980 | 0.21712 | 0.12361 | 0.05750 |
| 11 | 55503 | -0.01900 | 0.12534 | 0.10824 | 0.05610 |
| 12 | 55478 | 0.01217 | 0.01643 | 0.07840 | -0.04900 |
| 13 | 55523 | 0.06030 | 0.15103 | 0.17672 | 0.06870 |
| 14 | 55493 | 0.02520 | 0.15462 | 0.09770 | 0.00864 |
| 15 | 55547 | 0.07571 | 0.13140 | 0.19480 | 0.09810 |
| 16 | 72089 | 0.08609 | -0.01400 | 0.10679 | 0.02140 |
| 17 | 72042 | -0.03000 | -0.02000 | 0.06640 | -0.06600 |
| 18 | 72071 | 0.04090 | 0.05660 | 0.12524 | 0.01880 |
| 19 | 72055 | 0.00758 | 0.07622 | 0.08180 | -0.07900 |
| 20 | 72077 | 0.06040 | 0.02600 | 0.08790 | -0.01000 |
| 21 | 83421 | -0.02900 | 0.04120 | 0.07513 | -0.00940 |
| 22 | 83408 | 0.00372 | -0.01400 | 0.05270 | -0.06600 |
| 23 | 83376 | 0.00679 | -0.02500 | -0.00470 | -0.03000 |
| 24 | 83392 | 0.05740 | 0.01770 | 0.06010 | -0.00490 |
| 25 | 83436 | -0.05400 | 0.09140 | 0.10801 | -0.03900 |
| | | **** Average Data **** | | | |
| 26 | 36144 | 0.05635 | 0.09120 | 0.17664 | 0.09520 |
| 27 | 44553 | 0.06930 | 0.15093 | 0.12256 | 0.09100 |
| 28 | 55509 | 0.03080 | 0.11576 | 0.13116 | 0.03650 |
| 29 | 72067 | 0.03200 | 0.02510 | 0.09360 | -0.02500 |
| 30 | 83407 | -0.00310 | 0.02220 | 0.05830 | -0.03200 |
| | | **** Standard Deviation **** | | | |
| 31 | 36144 | 0.06830 | 0.09650 | 0.03490 | 0.05920 |
| 32 | 44553 | 0.04720 | 0.06230 | 0.00531 | 0.02450 |
| 33 | 55509 | 0.03770 | 0.05670 | 0.05094 | 0.05730 |
| 34 | 72067 | 0.04520 | 0.04240 | 0.02270 | 0.04650 |
| 35 | 83407 | 0.04230 | 0.04640 | 0.04080 | 0.02520 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 26.35, C/D= 20.15
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$ | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36070 | 0.33321 | 0.39524 | 0.53035 | 0.37825 |
| 2 | 36067 | 0.38931 | 0.37475 | 0.45674 | 0.25659 |
| 3 | 36026 | 0.23391 | 0.32677 | 0.42968 | 0.42118 |
| 4 | 36015 | 0.29696 | 0.34381 | 0.44176 | 0.28596 |
| 5 | 36028 | 0.35581 | 0.22219 | 0.45008 | 0.48119 |
| 6 | 44390 | 0.22858 | 0.46779 | 0.30687 | 0.27819 |
| 7 | 44354 | 0.25153 | 0.19274 | 0.30987 | 0.23404 |
| 8 | 44390 | 0.32257 | 0.50932 | 0.42987 | 0.39403 |
| 9 | 44370 | 0.26519 | 0.46529 | 0.39337 | 0.30804 |
| 10 | 44396 | 0.27517 | 0.35878 | 0.38142 | 0.36724 |
| 11 | 55579 | 0.18679 | 0.25442 | 0.25957 | 0.20325 |
| 12 | 55575 | 0.21033 | 0.35512 | 0.30008 | 0.13026 |
| 13 | 55568 | 0.25906 | 0.30588 | 0.33743 | 0.19518 |
| 14 | 55582 | 0.22875 | 0.24051 | 0.36521 | 0.17997 |
| 15 | 55581 | 0.20414 | 0.23111 | 0.38783 | 0.19850 |
| 16 | 72270 | 0.15438 | 0.21566 | 0.21097 | 0.09990 |
| 17 | 72271 | 0.19714 | 0.18235 | 0.23221 | 0.13921 |
| 18 | 72315 | 0.21554 | 0.25239 | 0.26337 | 0.10453 |
| 19 | 72278 | 0.22867 | 0.21196 | 0.28542 | 0.11997 |
| 20 | 72293 | 0.21369 | 0.21077 | 0.31597 | 0.14042 |
| 21 | 83165 | 0.13944 | 0.25935 | 0.24307 | 0.14619 |
| 22 | 83181 | 0.20593 | 0.24840 | 0.27288 | 0.15536 |
| 23 | 83188 | 0.17356 | 0.29918 | 0.30279 | 0.18533 |
| 24 | 83166 | 0.15639 | 0.23100 | 0.22651 | 0.13498 |
| 25 | 83176 | 0.24141 | 0.24691 | 0.31753 | 0.18341 |
| | | **** Average Data **** | | | |
| 26 | 36041 | 0.32183 | 0.33254 | 0.46171 | 0.36462 |
| 27 | 44380 | 0.26860 | 0.39879 | 0.36428 | 0.31631 |
| 28 | 55577 | 0.21781 | 0.27741 | 0.33002 | 0.18143 |
| 29 | 72285 | 0.20188 | 0.21463 | 0.26160 | 0.12081 |
| 30 | 83175 | 0.18335 | 0.25696 | 0.27256 | 0.16105 |
| | | **** Standard Deviation **** | | | |
| 31 | 36041 | 0.05920 | 0.06690 | 0.03930 | 0.09350 |
| 32 | 44380 | 0.03480 | 0.12771 | 0.05396 | 0.06480 |
| 33 | 55577 | 0.02760 | 0.05220 | 0.05120 | 0.02990 |
| 34 | 72285 | 0.02869 | 0.02470 | 0.04160 | 0.01890 |
| 35 | 83175 | 0.04070 | 0.02560 | 0.03840 | 0.02240 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.5990338
Orifice Plate Axial Position Z/D= 37.97, C/D= 31.77
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100 | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36225 | 0.13695 | 0.09720 | 0.23502 | 0.15404 |
| 2 | 36227 | 0.22555 | 0.03549 | 0.23162 | -0.00290 |
| 3 | 36229 | 0.25082 | 0.24712 | 0.22318 | 0.19449 |
| 4 | 36213 | 0.30257 | 0.29213 | 0.32507 | 0.08130 |
| 5 | 36208 | 0.18630 | 0.35022 | 0.12277 | 0.26128 |
| 6 | 44413 | 0.20684 | 0.03480 | 0.09440 | 0.17361 |
| 7 | 44450 | 0.30924 | 0.23571 | 0.20684 | 0.04390 |
| 8 | 44421 | 0.26094 | 0.30054 | 0.18881 | 0.11180 |
| 9 | 44422 | 0.18200 | 0.15081 | 0.11362 | 0.24290 |
| 10 | 44424 | 0.15431 | 0.39772 | 0.25235 | 0.18904 |
| 11 | 55435 | 0.16678 | 0.10383 | 0.13846 | 0.23306 |
| 12 | 55413 | 0.14808 | 0.17412 | 0.20044 | 0.12057 |
| 13 | 55436 | 0.21686 | 0.04220 | 0.23366 | 0.03110 |
| 14 | 55434 | 0.24855 | 0.26923 | 0.21908 | 0.08740 |
| 15 | 55396 | 0.15131 | 0.16606 | 0.16816 | 0.05750 |
| 16 | 72109 | 0.12509 | 0.23072 | 0.24135 | 0.13267 |
| 17 | 72084 | 0.14606 | 0.17012 | 0.18157 | 0.12282 |
| 18 | 72067 | 0.17768 | 0.05980 | 0.18667 | 0.09000 |
| 19 | 72091 | 0.16539 | 0.12760 | 0.19405 | 0.09360 |
| 20 | 72072 | 0.15347 | 0.11477 | 0.20581 | 0.08270 |
| 21 | 83400 | 0.14934 | 0.27528 | 0.18885 | 0.11452 |
| 22 | 83395 | 0.15837 | 0.25966 | 0.22052 | 0.27865 |
| 23 | 83383 | 0.14174 | 0.20191 | 0.19377 | 0.14677 |
| 24 | 83373 | 0.13674 | 0.15906 | 0.17535 | 0.05550 |
| 25 | 83382 | 0.18698 | 0.15481 | 0.15591 | 0.13700 |
| | | **** Average Data **** | | | |
| 26 | 36220 | 0.22043 | 0.20443 | 0.22753 | 0.13764 |
| 27 | 44426 | 0.22266 | 0.22393 | 0.17121 | 0.15226 |
| 28 | 55423 | 0.18631 | 0.15108 | 0.19195 | 0.10593 |
| 29 | 72085 | 0.15353 | 0.14060 | 0.20189 | 0.10455 |
| 30 | 83386 | 0.15463 | 0.21015 | 0.18688 | 0.14647 |
| | | **** Standard Deviation **** | | | |
| 31 | 36220 | 0.06290 | 0.13319 | 0.07169 | 0.10218 |
| 32 | 44426 | 0.06215 | 0.13895 | 0.06580 | 0.07670 |
| 33 | 55423 | 0.04420 | 0.08490 | 0.03860 | 0.07840 |
| 34 | 72085 | 0.02010 | 0.06370 | 0.02370 | 0.02166 |
| 35 | 83386 | 0.01980 | 0.05560 | 0.02377 | 0.08190 |

## Change in Orifice Meter Discharge Coefficients for a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D and Beta = 0.5990338

Orifice Plate Axial Position Z/D= 55.44, C/D= 49.20
Orifice Plate: Hole Diameter, d= 31.5 mm (1.24")

|  |  | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$<br>At Pressure Tap Positions |  |  |  |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 36129 | 0.01820 | 0.13739 | 0.17674 | 0.16797 |
| 2 | 36113 | 0.04100 | 0.09440 | 0.16827 | 0.10083 |
| 3 | 36073 | 0.01910 | 0.04003 | -0.02900 | -0.02000 |
| 4 | 36094 | 0.08860 | -0.02000 | 0.12959 | 0.08180 |
| 5 | 36095 | 0.07925 | -0.12791 | 0.08380 | -0.06300 |
| 6 | 44436 | 0.06260 | 0.04339 | -0.01800 | -0.07400 |
| 7 | 44449 | -0.05232 | 0.00070 | 0.05940 | -0.15063 |
| 8 | 44448 | -0.08200 | 0.13899 | -0.10641 | -0.33732 |
| 9 | 44459 | 0.00367 | -0.00160 | 0.07100 | 0.01170 |
| 10 | 44454 | 0.03440 | -0.00350 | 0.06010 | -0.13301 |
| 11 | 55553 | 0.06470 | 0.02390 | 0.00221 | -0.10305 |
| 12 | 55550 | 0.02490 | -0.08900 | 0.02956 | -0.09479 |
| 13 | 55533 | -0.05000 | -0.10052 | -0.07200 | -0.16101 |
| 14 | 55524 | -0.00970 | -0.15716 | -0.02600 | -0.18208 |
| 15 | 55525 | 0.00657 | -0.13180 | 0.04440 | -0.03100 |
| 16 | 72261 | 0.05460 | 0.00784 | 0.06430 | 0.00778 |
| 17 | 72173 | -0.02300 | -0.08800 | -0.05100 | -0.05500 |
| 18 | 72136 | 0.01280 | -0.01500 | -0.02000 | -0.05500 |
| 19 | 72184 | -0.01700 | -0.03800 | 0.01930 | -0.04100 |
| 20 | 72176 | -0.05100 | -0.06400 | -0.03655 | -0.07400 |
| 21 | 83136 | 0.02200 | 0.03810 | 0.06540 | -0.01000 |
| 22 | 83113 | -0.00910 | -0.01091 | 0.01140 | 0.05820 |
| 23 | 83142 | 0.01050 | 0.07040 | 0.07010 | 0.04230 |
| 24 | 83150 | -0.00800 | -0.04900 | -0.01700 | 0.04260 |
| 25 | 83137 | -0.02900 | 0.03070 | -0.04000 | -0.01200 |
|  |  | **** Average Data **** |  |  |  |
| 26 | 36101 | 0.04940 | 0.02470 | 0.10590 | 0.05340 |
| 27 | 44449 | -0.00680 | 0.03560 | 0.01330 | -0.13669 |
| 28 | 55537 | 0.00532 | -0.09100 | -0.00430 | -0.11442 |
| 29 | 72186 | -0.00480 | -0.03900 | -0.00480 | -0.04300 |
| 30 | 83135 | -0.00280 | 0.01590 | 0.01790 | 0.02420 |
|  |  | **** Standard Deviation **** |  |  |  |
| 31 | 36101 | 0.03320 | 0.10357 | 0.08350 | 0.09357 |
| 32 | 44449 | 0.06000 | 0.06100 | 0.07570 | 0.12881 |
| 33 | 55537 | 0.04570 | 0.06930 | 0.04630 | 0.05950 |
| 34 | 72186 | 0.03980 | 0.03790 | 0.04620 | 0.03030 |
| 35 | 83135 | 0.02020 | 0.04640 | 0.04900 | 0.03280 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 8.92, C/D= 2.72
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], ($C_d/C_{d,s}$-1)*100<br>At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44540 | -2.90613 | -3.22274 | -3.24892 | -2.97343 |
| 2 | 44561 | -3.01263 | -3.17986 | -3.04817 | -3.17288 |
| 3 | 44535 | -3.04934 | -3.25346 | -3.28921 | -2.89987 |
| 4 | 44558 | -3.13494 | -3.34015 | -3.01971 | -3.09928 |
| 5 | 44531 | -3.06801 | -3.09309 | -3.04914 | -3.02631 |
| 6 | 55448 | -3.00413 | -3.31062 | -3.25594 | -3.13825 |
| 7 | 55438 | -3.04576 | -3.16147 | -3.20557 | -3.10585 |
| 8 | 55421 | -3.02267 | -3.25169 | -3.18453 | -3.03195 |
| 9 | 55391 | -3.07926 | -3.34662 | -3.23381 | -2.87428 |
| 10 | 55397 | -3.09604 | -3.23001 | -3.12815 | -2.91353 |
| 11 | 72742 | -3.18346 | -3.16834 | -3.25796 | -3.06677 |
| 12 | 72759 | -3.20562 | -3.24425 | -3.25844 | -2.90406 |
| 13 | 72749 | -3.23698 | -3.14964 | -3.22380 | -2.75663 |
| 14 | 72744 | -3.20577 | -3.07610 | -3.24760 | -3.14117 |
| 15 | 72730 | -3.21589 | -3.13002 | -3.29425 | -2.93931 |
| 16 | 83206 | -3.08389 | -3.15238 | -3.18444 | -2.83213 |
| 17 | 83200 | -3.20457 | -3.14356 | -3.13463 | -3.05072 |
| 18 | 83201 | -3.19072 | -3.18806 | -3.07721 | -3.00579 |
| 19 | 83236 | -3.26857 | -3.09441 | -3.13981 | -2.85632 |
| 20 | 83204 | -3.17120 | -3.08176 | -3.20347 | -2.90469 |
| 21 | 98773 | -3.13932 | -3.04649 | -3.18591 | -3.25912 |
| 22 | 98767 | -3.11451 | -3.14465 | -3.21537 | -3.26038 |
| 23 | 98818 | -3.14381 | -3.02095 | -3.20966 | -3.22998 |
| 24 | 98835 | -3.22170 | -2.94939 | -3.05398 | -3.09245 |
| 25 | 98798 | -3.14666 | -2.99202 | -3.15609 | -3.22364 |
| | | **** Average Data **** | | | |
| 26 | 44545 | -3.03421 | -3.21787 | -3.13103 | -3.03436 |
| 27 | 55419 | -3.04957 | -3.26008 | -3.20150 | -3.01276 |
| 28 | 72745 | -3.20955 | -3.15360 | -3.25641 | -2.96150 |
| 29 | 83209 | -3.18381 | -3.13204 | -3.14791 | -2.92993 |
| 30 | 98798 | -3.15322 | -3.03069 | -3.16410 | -3.21311 |
| | | **** Standard Deviation **** | | | |
| 31 | 44545 | 0.08430 | 0.09140 | 0.12717 | 0.10667 |
| 32 | 55419 | 0.03770 | 0.07180 | 0.04950 | 0.11657 |
| 33 | 72745 | 0.01940 | 0.06140 | 0.02530 | 0.14921 |
| 34 | 83209 | 0.06690 | 0.04350 | 0.04920 | 0.09470 |
| 35 | 98798 | 0.04080 | 0.07280 | 0.06560 | 0.06910 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 14.73, C/D= 8.53
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100<br>At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44563 | -0.77383 | -0.75390 | -0.50606 | -0.52620 |
| 2 | 44536 | -0.58357 | -0.50749 | -0.44279 | -0.61020 |
| 3 | 44526 | -0.72386 | -0.67769 | -0.42438 | -0.68810 |
| 4 | 44534 | -0.64333 | -0.71677 | -0.29781 | -0.48753 |
| 5 | 44538 | -0.50342 | -0.73582 | -0.40152 | -0.59140 |
| 6 | 55772 | -0.79213 | -0.82800 | -0.63801 | -0.75251 |
| 7 | 55836 | -0.57506 | -0.89235 | -0.37801 | -0.83636 |
| 8 | 55751 | -0.72555 | -0.74702 | -0.71557 | -0.65027 |
| 9 | 55774 | -0.65534 | -0.64508 | -0.51114 | -0.78313 |
| 10 | 55728 | -0.62535 | -0.97800 | -0.49409 | -0.88367 |
| 11 | 72341 | -0.63729 | -0.73329 | -0.62551 | -0.83006 |
| 12 | 72313 | -0.64085 | -0.77787 | -0.72367 | -0.66569 |
| 13 | 72306 | -0.73445 | -0.69854 | -0.65432 | -0.80283 |
| 14 | 72335 | -0.65550 | -0.86911 | -0.60314 | -0.75440 |
| 15 | 72333 | -0.70968 | -0.83231 | -0.57336 | -0.88307 |
| 16 | 83312 | -0.67463 | -0.58747 | -0.69118 | -0.74148 |
| 17 | 83315 | -0.67499 | -0.77666 | -0.62104 | -0.75870 |
| 18 | 83272 | -0.70463 | -0.59729 | -0.64626 | -0.79731 |
| 19 | 83294 | -0.70621 | -0.64449 | -0.65777 | -0.78976 |
| 20 | 83282 | -0.73658 | -0.57980 | -0.67431 | -0.90035 |
| 21 | 98575 | -0.75773 | -0.61535 | -0.56573 | -0.58309 |
| 22 | 98595 | -0.65736 | -0.59919 | -0.56346 | -0.78387 |
| 23 | 98644 | -0.71866 | -0.54158 | -0.55046 | -0.66738 |
| 24 | 98611 | -0.72053 | -0.60007 | -0.58663 | -0.73951 |
| 25 | 98657 | -0.70551 | -0.67202 | -0.50826 | -0.64045 |
| | | **** Average Data **** | | | |
| 26 | 44539 | -0.64559 | -0.67832 | -0.41452 | -0.58068 |
| 27 | 55772 | -0.67469 | -0.81809 | -0.54736 | -0.78119 |
| 28 | 72326 | -0.67556 | -0.78222 | -0.63599 | -0.78722 |
| 29 | 83295 | -0.69941 | -0.63714 | -0.65811 | -0.79752 |
| 30 | 98617 | -0.71195 | -0.60564 | -0.55490 | -0.68286 |
| | | **** Standard Deviation **** | | | |
| 31 | 44539 | 0.10813 | 0.09970 | 0.07620 | 0.07750 |
| 32 | 55772 | 0.08490 | 0.12856 | 0.13111 | 0.08890 |
| 33 | 72326 | 0.04374 | 0.06990 | 0.05710 | 0.08250 |
| 34 | 83295 | 0.02550 | 0.08216 | 0.02677 | 0.06160 |
| 35 | 98617 | 0.03610 | 0.04660 | 0.02870 | 0.07970 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 20.54, C/D= 14.34
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

$\Delta C_d[\%]$, $(C_d/C_{d,s}-1)*100$
At Pressure Tap Positions

| No. | Re | 0° | 90° | 180° | 270° |
|---|---|---|---|---|---|
| 1 | 44497 | 0.22325 | 0.30932 | 0.43488 | 0.46188 |
| 2 | 44520 | 0.29751 | 0.42471 | 0.50134 | 0.39343 |
| 3 | 44516 | 0.41247 | 0.19290 | 0.57561 | 0.35346 |
| 4 | 44533 | 0.32301 | 0.49105 | 0.52797 | 0.37273 |
| 5 | 44514 | 0.25644 | 0.24813 | 0.46668 | 0.23090 |
| 6 | 55570 | 0.21375 | 0.07640 | 0.38799 | 0.14187 |
| 7 | 55578 | 0.11187 | 0.25768 | 0.42143 | 0.10346 |
| 8 | 55599 | 0.27531 | 0.35982 | 0.42288 | 0.23897 |
| 9 | 55592 | 0.15657 | 0.30348 | 0.47513 | 0.16046 |
| 10 | 55567 | 0.24559 | 0.22656 | 0.37984 | 0.02420 |
| 11 | 71883 | 0.13522 | 0.36236 | 0.34347 | 0.27454 |
| 12 | 71909 | 0.06330 | 0.19853 | 0.41772 | 0.18061 |
| 13 | 71895 | 0.14832 | 0.30893 | 0.41031 | 0.32936 |
| 14 | 71930 | 0.19077 | 0.23471 | 0.38175 | 0.21323 |
| 15 | 71900 | 0.13775 | 0.08640 | 0.47103 | 0.36933 |
| 16 | 83068 | 0.17413 | 0.12201 | 0.34751 | 0.17620 |
| 17 | 83095 | 0.08520 | 0.23709 | 0.37380 | 0.01660 |
| 18 | 83113 | 0.12274 | 0.18784 | 0.37186 | 0.22560 |
| 19 | 83109 | 0.21914 | 0.23552 | 0.44076 | 0.16632 |
| 20 | 83070 | 0.14109 | 0.31789 | 0.39256 | 0.24209 |
| 21 | 98933 | 0.15791 | 0.33718 | 0.34591 | 0.23329 |
| 22 | 98969 | 0.06560 | 0.31967 | 0.36659 | 0.09900 |
| 23 | 98934 | 0.15174 | 0.26962 | 0.42811 | 0.19973 |
| 24 | 98968 | 0.10240 | 0.25466 | 0.37515 | 0.07030 |
| 25 | 98927 | 0.18388 | 0.19229 | 0.45397 | 0.16791 |
| | | **** Average Data **** | | | |
| 26 | 44516 | 0.30253 | 0.33322 | 0.50130 | 0.36249 |
| 27 | 55581 | 0.20062 | 0.24478 | 0.41746 | 0.13379 |
| 28 | 71903 | 0.13507 | 0.23819 | 0.40486 | 0.27341 |
| 29 | 83091 | 0.14846 | 0.22006 | 0.38529 | 0.16536 |
| 30 | 98946 | 0.13230 | 0.27468 | 0.39396 | 0.15405 |
| | | **** Standard Deviation **** | | | |
| 31 | 44516 | 0.07220 | 0.12307 | 0.05420 | 0.08430 |
| 32 | 55581 | 0.06630 | 0.10643 | 0.03730 | 0.07840 |
| 33 | 71903 | 0.04580 | 0.10626 | 0.04710 | 0.07860 |
| 34 | 83091 | 0.05092 | 0.07200 | 0.03470 | 0.08910 |
| 35 | 98946 | 0.04780 | 0.05720 | 0.04540 | 0.06850 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 26.35, C/D= 20.15
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$<br>At Pressure Tap Positions | | | |
|---|---|---|---|---|---|
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44444 | 0.57060 | 0.45976 | 0.62477 | 0.74749 |
| 2 | 44420 | 0.60236 | 0.54257 | 0.69747 | 0.58261 |
| 3 | 44424 | 0.63017 | 0.72500 | 0.74081 | 0.39402 |
| 4 | 44405 | 0.63630 | 0.32553 | 0.65118 | 0.56537 |
| 5 | 44445 | 0.64133 | 0.37806 | 0.78361 | 0.51686 |
| 6 | 55625 | 0.48533 | 0.31070 | 0.53282 | 0.41507 |
| 7 | 55649 | 0.56206 | 0.22542 | 0.51797 | 0.33048 |
| 8 | 55641 | 0.42978 | 0.57970 | 0.67279 | 0.36273 |
| 9 | 55616 | 0.47940 | 0.33013 | 0.52338 | 0.30239 |
| 10 | 55628 | 0.50670 | 0.61871 | 0.54631 | 0.58432 |
| 11 | 71816 | 0.42926 | 0.14198 | 0.60051 | 0.27924 |
| 12 | 71863 | 0.51698 | 0.37478 | 0.65513 | 0.45005 |
| 13 | 71863 | 0.35662 | 0.32421 | 0.58616 | 0.44286 |
| 14 | 71831 | 0.40403 | 0.43123 | 0.50114 | 0.17431 |
| 15 | 71913 | 0.46368 | 0.42296 | 0.59641 | 0.59369 |
| 16 | 83194 | 0.50012 | 0.52543 | 0.56896 | 0.48388 |
| 17 | 83159 | 0.43092 | 0.44646 | 0.53408 | 0.39641 |
| 18 | 83184 | 0.34642 | 0.24991 | 0.57782 | 0.33147 |
| 19 | 83176 | 0.45604 | 0.44730 | 0.62340 | 0.30730 |
| 20 | 83116 | 0.38907 | 0.32257 | 0.49297 | 0.25710 |
| 21 | 98598 | 0.38195 | 0.43480 | 0.56373 | 0.50383 |
| 22 | 98603 | 0.45853 | 0.25422 | 0.54559 | 0.35690 |
| 23 | 98650 | 0.49357 | 0.36741 | 0.62641 | 0.34295 |
| 24 | 98630 | 0.41111 | 0.45120 | 0.59743 | 0.48661 |
| 25 | 98564 | 0.32651 | 0.40130 | 0.56291 | 0.30163 |
| | | **** Average Data **** | | | |
| 26 | 44428 | 0.61615 | 0.48618 | 0.69958 | 0.56128 |
| 27 | 55632 | 0.49265 | 0.41293 | 0.55866 | 0.39899 |
| 28 | 71857 | 0.43411 | 0.33904 | 0.58787 | 0.38804 |
| 29 | 83166 | 0.42450 | 0.39832 | 0.55945 | 0.35522 |
| 30 | 98609 | 0.41434 | 0.38179 | 0.57922 | 0.39840 |
| | | **** Standard Deviation **** | | | |
| 31 | 44428 | 0.02970 | 0.15686 | 0.06450 | 0.12743 |
| 32 | 55632 | 0.04790 | 0.17510 | 0.06460 | 0.11178 |
| 33 | 71857 | 0.06030 | 0.11771 | 0.05520 | 0.16257 |
| 34 | 83166 | 0.05920 | 0.11006 | 0.04850 | 0.08730 |
| 35 | 98609 | 0.06480 | 0.07820 | 0.03100 | 0.09080 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 37.97, C/D= 31.77
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

$\Delta C_d$[%], $(C_d/C_{d,s}-1)*100$
At Pressure Tap Positions

| No. | Re | 0° | 90° | 180° | 270° |
|---|---|---|---|---|---|
| 1 | 44504 | 0.50952 | 0.23913 | 0.74489 | 0.40291 |
| 2 | 44528 | 0.47893 | 0.34309 | 0.65711 | 0.53623 |
| 3 | 44525 | 0.45549 | 0.39719 | 0.66642 | 0.47954 |
| 4 | 44525 | 0.31524 | 0.51881 | 0.59308 | 0.34789 |
| 5 | 44525 | 0.44406 | 0.60026 | 0.64942 | 0.50012 |
| 6 | 55658 | 0.36749 | 0.62314 | 0.45506 | 0.26346 |
| 7 | 55655 | 0.36602 | 0.12844 | 0.38684 | 0.17046 |
| 8 | 55645 | 0.40117 | 0.06940 | 0.35178 | 0.26379 |
| 9 | 55628 | 0.26237 | -0.15292 | 0.32949 | 0.37012 |
| 10 | 55612 | 0.25807 | 0.53414 | 0.46304 | 0.12463 |
| 11 | 72063 | 0.17630 | -0.19991 | 0.50983 | 0.26497 |
| 12 | 72120 | 0.30449 | 0.29929 | 0.42014 | 0.38946 |
| 13 | 72098 | 0.32558 | 0.37549 | 0.48395 | 0.31962 |
| 14 | 72110 | 0.30974 | 0.05700 | 0.43243 | 0.12823 |
| 15 | 72105 | 0.22381 | 0.46305 | 0.42803 | 0.20851 |
| 16 | 83132 | 0.28234 | 0.15729 | 0.42192 | 0.18465 |
| 17 | 83171 | 0.22787 | 0.19467 | 0.42106 | 0.20137 |
| 18 | 83051 | 0.31633 | 0.32692 | 0.40560 | 0.32066 |
| 19 | 83153 | 0.25607 | 0.32207 | 0.39881 | 0.23507 |
| 20 | 83140 | 0.34177 | 0.23903 | 0.42254 | 0.31845 |
| 21 | 99072 | 0.30627 | 0.30894 | 0.42810 | 0.40414 |
| 22 | 99030 | 0.21968 | 0.35016 | 0.42596 | 0.25160 |
| 23 | 99015 | 0.28443 | 0.39707 | 0.45757 | 0.32202 |
| 24 | 98981 | 0.34552 | 0.36509 | 0.42636 | 0.20037 |
| 25 | 99009 | 0.26502 | 0.40871 | 0.41847 | 0.30975 |
| | | **** Average Data **** | | | |
| 26 | 44521 | 0.44065 | 0.41970 | 0.66219 | 0.45334 |
| 27 | 55640 | 0.33103 | 0.24044 | 0.39724 | 0.23850 |
| 28 | 72099 | 0.26799 | 0.19917 | 0.45488 | 0.26216 |
| 29 | 83129 | 0.28488 | 0.24800 | 0.41398 | 0.25205 |
| 30 | 99022 | 0.28418 | 0.36599 | 0.43128 | 0.29757 |
| | | **** Standard Deviation **** | | | |
| 31 | 44521 | 0.07460 | 0.14250 | 0.05460 | 0.07640 |
| 32 | 55640 | 0.06580 | 0.32757 | 0.06012 | 0.09503 |
| 33 | 72099 | 0.06440 | 0.26891 | 0.04010 | 0.10038 |
| 34 | 83129 | 0.04610 | 0.07605 | 0.01080 | 0.06480 |
| 35 | 99022 | 0.04699 | 0.04000 | 0.01520 | 0.07650 |

Change in Orifice Meter Discharge Coefficients for
a Header H342-100/0-1 with a 19-Tube Bundle at 6.2D
and Beta = 0.7487923
Orifice Plate Axial Position Z/D= 55.44, C/D= 49.20
Orifice Plate: Hole Diameter, d= 39.4 mm (1.55")

| | | $\Delta C_d$[%], $(C_d/C_{d,s}-1)$*100 | | | |
|---|---|---|---|---|---|
| | | At Pressure Tap Positions | | | |
| No. | Re | 0° | 90° | 180° | 270° |
| 1 | 44664 | 0.03420 | -0.35143 | 0.11689 | 0.28104 |
| 2 | 44630 | -0.03300 | 0.26957 | 0.28564 | -0.15390 |
| 3 | 44613 | 0.10249 | -0.06500 | 0.16486 | -0.00210 |
| 4 | 44617 | 0.07230 | 0.13202 | 0.21147 | 0.03030 |
| 5 | 44606 | 0.04932 | -0.15831 | 0.06640 | -0.28344 |
| 6 | 55524 | -0.05600 | -0.05100 | 0.17741 | 0.00187 |
| 7 | 55482 | 0.08270 | 0.24122 | -0.03500 | -0.55416 |
| 8 | 55530 | 0.09490 | 0.10560 | 0.21113 | -0.13747 |
| 9 | 55506 | 0.01340 | -0.05100 | -0.04300 | -0.26932 |
| 10 | 55490 | -0.03500 | -0.12546 | 0.11361 | -0.21183 |
| 11 | 72154 | -0.05800 | -0.28101 | 0.17504 | -0.27529 |
| 12 | 72116 | -0.01300 | -0.30977 | 0.15835 | -0.07000 |
| 13 | 72139 | 0.05020 | 0.00810 | 0.16471 | 0.06700 |
| 14 | 72095 | 0.03090 | -0.12431 | 0.07690 | 0.03740 |
| 15 | 72113 | -0.05500 | -0.14255 | 0.18374 | 0.20238 |
| 16 | 83258 | -0.02300 | 0.20953 | 0.05860 | -0.02400 |
| 17 | 83145 | -0.01700 | 0.11918 | 0.14311 | -0.11038 |
| 18 | 83153 | -0.00860 | 0.08176 | 0.14250 | -0.21535 |
| 19 | 83094 | 0.05030 | -0.02000 | 0.13429 | -0.24331 |
| 20 | 83088 | -0.04400 | 0.04450 | 0.10966 | -0.15842 |
| 21 | 99166 | 0.01060 | 0.10561 | 0.05610 | 0.04180 |
| 22 | 99142 | -0.04266 | -0.05800 | 0.15290 | -0.10839 |
| 23 | 99206 | 0.01610 | 0.05530 | 0.17682 | -0.04400 |
| 24 | 99191 | 0.01210 | 0.18084 | 0.21026 | 0.01950 |
| 25 | 99188 | 0.00731 | 0.06920 | 0.08870 | -0.08600 |
| | | **** Average Data **** | | | |
| 26 | 44626 | 0.04520 | -0.03500 | 0.16906 | -0.02600 |
| 27 | 55506 | 0.02000 | 0.02385 | 0.08490 | -0.23418 |
| 28 | 72123 | -0.00890 | -0.16990 | 0.15175 | -0.00940 |
| 29 | 83147 | -0.00860 | 0.08510 | 0.11762 | -0.15032 |
| 30 | 99179 | 0.00070 | 0.07060 | 0.13695 | -0.03500 |
| | | **** Standard Deviation **** | | | |
| 31 | 44626 | 0.05070 | 0.24361 | 0.08460 | 0.21203 |
| 32 | 55506 | 0.06770 | 0.14794 | 0.11792 | 0.20525 |
| 33 | 72123 | 0.04910 | 0.12895 | 0.04260 | 0.17965 |
| 34 | 83147 | 0.03590 | 0.08750 | 0.03662 | 0.08620 |
| 35 | 99179 | 0.02410 | 0.08650 | 0.06330 | 0.06502 |

# APPENDIX C

## Turbine Flow Meter Performance for a Header H342-100/0-1 with and without a 19-tube bundle

## Meters in the Outlet Pipe #1 with the Outlet #1 Opened and the Outlet #2 Fully Closed

Tube Bundle Entrance Location, Z= 4.26D
Tube Bundle Exit Location, Z= 6.2D
Water Temperature =21.5 °C
Gage Pressure = 138 kPa (20 PSI)
Water Density = 997.88 kg/m$^3$
Water Kinematic Viscosity = 9.71958*10$^{-7}$
Meter Tube Diameter, D= 52.5 mm (2.07")

Change in Turbine Meter Constant for
Header H342-100/0-1

$\Delta S_t$, [%] = $(S_t/S_{t,s}-1)*100$

| No. | Re | $\Delta S_t$ | Re | $\Delta S_t$ | Re | $\Delta S_t$ |
|---|---|---|---|---|---|---|
| | (Z = 3.52 D) | | (Z = 9.32 D) | | (Z= 15.14 D) | |
| 1 | 44420 | 0.31779 | 44531 | 0.35006 | 44513 | 0.30057 |
| 2 | 44414 | 0.37954 | 44531 | 0.34087 | 44457 | 0.30861 |
| 3 | 44399 | 0.34871 | 44552 | 0.41022 | 44498 | 0.26915 |
| 4 | 44433 | 0.39806 | 44555 | 0.37596 | 44480 | 0.27818 |
| 5 | 44399 | 0.33643 | 44558 | 0.39383 | 44483 | 0.28487 |
| 6 | 55426 | 0.37403 | 55604 | 0.37647 | 55664 | 0.26668 |
| 7 | 55424 | 0.35216 | 55605 | 0.40453 | 55659 | 0.28068 |
| 8 | 55477 | 0.31299 | 55653 | 0.41909 | 55670 | 0.27366 |
| 9 | 55442 | 0.43389 | 55644 | 0.35610 | 55638 | 0.29840 |
| 10 | 55407 | 0.35839 | 55673 | 0.39596 | 55639 | 0.30868 |
| 11 | 72157 | 0.41658 | 72170 | 0.40496 | 72146 | 0.28684 |
| 12 | 72141 | 0.36351 | 72138 | 0.36262 | 71894 | 0.29462 |
| 13 | 72145 | 0.32398 | 72170 | 0.39309 | 71728 | 0.26845 |
| 14 | 72193 | 0.43316 | 72165 | 0.37693 | 71695 | 0.29897 |
| 15 | 72185 | 0.29444 | 72172 | 0.42202 | 71681 | 0.30649 |
| 16 | 83371 | 0.41384 | 83087 | 0.40338 | 83247 | 0.29356 |
| 17 | 83277 | 0.36045 | 83105 | 0.43108 | 83251 | 0.30334 |
| 18 | 83349 | 0.39373 | 82993 | 0.39270 | 83251 | 0.30923 |
| 19 | 83370 | 0.31186 | 82863 | 0.41764 | 83312 | 0.28035 |
| 20 | 83365 | 0.28663 | 82904 | 0.36916 | 83263 | 0.31678 |
| 21 | 98478 | 0.41403 | 98512 | 0.41666 | 98630 | 0.29153 |
| 22 | 98507 | 0.35582 | 98562 | 0.40219 | 98634 | 0.33361 |
| 23 | 98447 | 0.39005 | 98504 | 0.38924 | 98630 | 0.30549 |
| 24 | 98482 | 0.33771 | 98520 | 0.42851 | 98650 | 0.31962 |
| 25 | 98502 | 0.38056 | 98515 | 0.37017 | 98643 | 0.31205 |
| | | **** | Average Data | **** | | |
| 26 | 44413 | 0.35610 | 44545 | 0.37419 | 44486 | 0.28828 |
| 27 | 55435 | 0.36629 | 55636 | 0.39043 | 55654 | 0.28563 |
| 28 | 72164 | 0.36634 | 72163 | 0.39192 | 71829 | 0.29107 |
| 29 | 83346 | 0.35331 | 82990 | 0.40280 | 83265 | 0.30065 |
| 30 | 98483 | 0.37564 | 98523 | 0.40135 | 98637 | 0.31248 |
| | | **** | Standard Deviation | | **** | |
| 31 | 44413 | 0.03250 | 44545 | 0.02910 | 44486 | 0.01610 |
| 32 | 55435 | 0.04395 | 55636 | 0.02460 | 55654 | 0.01740 |
| 33 | 72164 | 0.05910 | 72163 | 0.02330 | 71829 | 0.01440 |
| 34 | 83346 | 0.05360 | 82990 | 0.02380 | 83265 | 0.01410 |
| 35 | 98483 | 0.02970 | 98523 | 0.02290 | 98637 | 0.01570 |

## Change in Turbine Meter Constant for Header H342-100/0-1

$$\Delta S_t, [\%] = (S_t/S_{t,s}-1)*100$$

| No. | Re | $\Delta S_t$ | Re | $\Delta S_t$ | Re | $\Delta S_t$ |
|---|---|---|---|---|---|---|
| | (Z = 26.76 D) | | (Z = 38.38 D) | | (Z= 50.00 D) | |
| 1 | 44552 | 0.21747 | 44408 | 0.13734 | 44550 | 0.09780 |
| 2 | 44545 | 0.22657 | 44400 | 0.17942 | 44515 | 0.16733 |
| 3 | 44553 | 0.23405 | 44397 | 0.20320 | 44544 | 0.13858 |
| 4 | 44563 | 0.25389 | 44447 | 0.16551 | 44554 | 0.09500 |
| 5 | 44582 | 0.24466 | 44400 | 0.21228 | 44528 | 0.11765 |
| 6 | 55811 | 0.21210 | 55799 | 0.18158 | 55675 | 0.15173 |
| 7 | 55719 | 0.24268 | 55786 | 0.20338 | 55645 | 0.14262 |
| 8 | 55745 | 0.26379 | 55807 | 0.16309 | 55653 | 0.15538 |
| 9 | 55759 | 0.21163 | 55788 | 0.17721 | 55640 | 0.11887 |
| 10 | 55743 | 0.22754 | 55786 | 0.21266 | 55656 | 0.10176 |
| 11 | 72160 | 0.24290 | 72035 | 0.20406 | 72070 | 0.15548 |
| 12 | 72186 | 0.20921 | 71954 | 0.19008 | 72102 | 0.13473 |
| 13 | 72171 | 0.23358 | 71821 | 0.23939 | 72110 | 0.11925 |
| 14 | 72170 | 0.22751 | 71859 | 0.16415 | 72111 | 0.10408 |
| 15 | 72165 | 0.25197 | 71844 | 0.18225 | 72098 | 0.12826 |
| 16 | 83040 | 0.25262 | 83341 | 0.21374 | 83269 | 0.12448 |
| 17 | 83074 | 0.23767 | 83370 | 0.20010 | 83369 | 0.16898 |
| 18 | 83067 | 0.24167 | 83378 | 0.16377 | 83384 | 0.13751 |
| 19 | 83058 | 0.23710 | 83365 | 0.18913 | 83343 | 0.16284 |
| 20 | 83076 | 0.22918 | 83353 | 0.23296 | 83353 | 0.15065 |
| 21 | 99024 | 0.23967 | 98891 | 0.19684 | 98997 | 0.16612 |
| 22 | 99022 | 0.23629 | 98824 | 0.23409 | 98973 | 0.15380 |
| 23 | 99029 | 0.26211 | 98818 | 0.22333 | 98997 | 0.18627 |
| 24 | 98991 | 0.25550 | 98821 | 0.20996 | 98978 | 0.13463 |
| 25 | 98994 | 0.24892 | 98871 | 0.17115 | 98985 | 0.14609 |
| | | **** | Average Data | | **** | |
| 26 | 44559 | 0.23532 | 44411 | 0.17956 | 44538 | 0.12328 |
| 27 | 55755 | 0.23155 | 55793 | 0.18758 | 55654 | 0.13407 |
| 28 | 72170 | 0.23304 | 71903 | 0.19598 | 72098 | 0.12836 |
| 29 | 83063 | 0.23965 | 83361 | 0.19994 | 83344 | 0.14890 |
| 30 | 99012 | 0.24850 | 98845 | 0.20708 | 98986 | 0.15737 |
| | | **** | Standard Deviation | | **** | |
| 31 | 44559 | 0.01440 | 44411 | 0.03000 | 44538 | 0.03020 |
| 32 | 55755 | 0.02200 | 55793 | 0.02012 | 55654 | 0.02300 |
| 33 | 72170 | 0.01620 | 71903 | 0.02820 | 72098 | 0.01800 |
| 34 | 83063 | 0.00852 | 83361 | 0.02500 | 83344 | 0.01830 |
| 35 | 99012 | 0.01070 | 98845 | 0.02440 | 98986 | 0.01980 |

## Change in Turbine Meter Constant for Header H342-100/0-1

$\Delta S_t, [\%] = (S_t/S_{t,s}-1)*100$

| No. | Re | $\Delta S_t$ |
|---|---|---|
| | (Z = 61.62 D) | |
| 1 | 44514 | 0.06990 |
| 2 | 44521 | 0.04780 |
| 3 | 44492 | 0.02626 |
| 4 | 44507 | 0.05420 |
| 5 | 44462 | 0.09420 |
| 6 | 55702 | 0.03970 |
| 7 | 55629 | 0.09973 |
| 8 | 55605 | 0.06520 |
| 9 | 55420 | 0.08670 |
| 10 | 55398 | 0.13056 |
| 11 | 72322 | 0.03510 |
| 12 | 72279 | 0.07580 |
| 13 | 72265 | 0.08870 |
| 14 | 72259 | 0.12429 |
| 15 | 72271 | 0.08670 |
| 16 | 83184 | 0.05380 |
| 17 | 83145 | 0.12775 |
| 18 | 83177 | 0.07400 |
| 19 | 83176 | 0.09330 |
| 20 | 83092 | 0.10911 |
| 21 | 98678 | 0.07330 |
| 22 | 98683 | 0.09660 |
| 23 | 98662 | 0.12080 |
| 24 | 98646 | 0.14686 |
| 25 | 98673 | 0.10521 |
| ** Average Data ** | | |
| 26 | 44499 | 0.05840 |
| 27 | 55551 | 0.08440 |
| 28 | 72279 | 0.08210 |
| 29 | 83155 | 0.09180 |
| 30 | 98669 | 0.10854 |
| ** Standard Deviation ** | | |
| 31 | 44499 | 0.02534 |
| 32 | 55551 | 0.03410 |
| 33 | 72279 | 0.03190 |
| 34 | 83155 | 0.02880 |
| 35 | 98669 | 0.02740 |

## Change in Turbine Meter Constants for
## Header H342-100/0-1 with a 19-Tube Bundle at 6.2D

$\Delta S_t,[\%] = (S_t/S_{t,s}-1)*100$

| No. | Re | $\Delta S_t$ | Re | $\Delta S_t$ | Re | $\Delta S_t$ |
|---|---|---|---|---|---|---|
| | (Z = 7.78 D) | | (Z = 13.59 D) | | (Z = 19.4 D) | |
| | (C = 1.58 D) | | (C = 7.39 D) | | (C = 13.2 D) | |
| 1 | 44394 | -0.04400 | 44417 | -0.04100 | 44427 | -0.01800 |
| 2 | 44374 | -0.03100 | 44438 | -0.01100 | 44460 | -0.04900 |
| 3 | 44379 | -0.00600 | 44400 | -0.05800 | 44469 | -0.00590 |
| 4 | 44370 | -0.02600 | 44430 | -0.09500 | 44449 | 0.01300 |
| 5 | 44371 | -0.01700 | 44387 | 0.00456 | 44439 | -0.03400 |
| 6 | 55514 | -0.05800 | 55362 | -0.04600 | 55493 | -0.02200 |
| 7 | 55529 | -0.07200 | 55340 | -0.01300 | 55488 | -0.01100 |
| 8 | 55502 | -0.02500 | 55359 | -0.08631 | 55506 | -0.04200 |
| 9 | 55478 | -0.03000 | 55346 | -0.06800 | 55434 | -0.03000 |
| 10 | 55502 | -0.05022 | 55306 | -0.03600 | 55442 | 0.01270 |
| 11 | 72280 | -0.07700 | 72215 | -0.04200 | 72402 | -0.04052 |
| 12 | 72272 | -0.06900 | 72187 | -0.07200 | 72381 | -0.07000 |
| 13 | 72268 | -0.08800 | 72194 | -0.05300 | 72345 | -0.00350 |
| 14 | 72243 | -0.04300 | 72195 | -0.10691 | 72355 | -0.02300 |
| 15 | 72226 | -0.04700 | 72187 | -0.08500 | 72351 | -0.04900 |
| 16 | 83289 | -0.08200 | 83250 | -0.03300 | 83298 | -0.04100 |
| 17 | 83264 | -0.07300 | 83260 | -0.03000 | 83308 | -0.01400 |
| 18 | 83290 | -0.06600 | 83223 | -0.05700 | 83304 | -0.04000 |
| 19 | 83284 | -0.09177 | 83242 | -0.07500 | 83316 | -0.02800 |
| 20 | 83254 | -0.02900 | 83251 | -0.09900 | 83336 | -0.08400 |
| 21 | 98879 | -0.09400 | 98901 | -0.08100 | 98658 | -0.05900 |
| 22 | 98875 | -0.03600 | 98885 | -0.03100 | 98652 | -0.02200 |
| 23 | 98897 | -0.07300 | 98836 | -0.09300 | 98642 | -0.03900 |
| 24 | 98876 | -0.06000 | 98838 | -0.10350 | 98661 | -0.08959 |
| 25 | 98830 | -0.06500 | 98851 | -0.05086 | 98658 | -0.04000 |
| | | **** | Average Data | **** | | |
| 26 | 44377 | -0.02500 | 44414 | -0.03000 | 44449 | -0.01856 |
| 27 | 55505 | -0.04700 | 55342 | -0.04000 | 55473 | -0.01800 |
| 28 | 72258 | -0.06500 | 72196 | -0.07200 | 72367 | -0.03901 |
| 29 | 83276 | -0.06839 | 83245 | -0.06100 | 83313 | -0.04300 |
| 30 | 98872 | -0.06700 | 98862 | -0.07200 | 98654 | -0.05200 |
| | | **** | Standard Deviation | **** | | |
| 31 | 44377 | 0.01420 | 44414 | 0.03920 | 44449 | 0.02440 |
| 32 | 55505 | 0.01940 | 55342 | 0.02840 | 55473 | 0.02080 |
| 33 | 72258 | 0.01930 | 72196 | 0.02590 | 72367 | 0.02860 |
| 34 | 83276 | 0.02410 | 83245 | 0.02690 | 83313 | 0.02660 |
| 35 | 98872 | 0.02098 | 98862 | 0.03010 | 98654 | 0.02520 |

## Change in Turbine Meter Constants for Header H342-100/0-1 with a 19-Tube Bundle at 6.2D

$\Delta S_t, [\%] = (S_t/S_{t,s}-1)*100$

| No. | Re | $\Delta S_t$ | Re | $\Delta S_t$ | Re | $\Delta S_t$ |
|---|---|---|---|---|---|---|
| | ( Z = 25.21 D) | | ( Z = 36.83 D) | | (Z = 54.26 D) | |
| | ( C = 19.01 D) | | ( C = 30.63 D) | | (C = 48.06 D) | |
| 1 | 44491 | -0.02800 | 44529 | 0.03840 | 44479 | -0.01800 |
| 2 | 44472 | -0.04700 | 44558 | -0.00640 | 44496 | 0.00748 |
| 3 | 44467 | -0.06500 | 44531 | -0.04800 | 44478 | 0.00233 |
| 4 | 44482 | -0.07400 | 44524 | -0.07900 | 44464 | 0.02050 |
| 5 | 44442 | -0.09100 | 44509 | 0.05250 | 44447 | 0.01430 |
| 6 | 55559 | -0.07493 | 55695 | -0.07400 | 55490 | -0.05500 |
| 7 | 55538 | -0.00490 | 55720 | -0.07000 | 55478 | 0.00286 |
| 8 | 55552 | -0.03200 | 55672 | 0.02930 | 55441 | 0.04040 |
| 9 | 55576 | 0.01130 | 55672 | 0.05680 | 55496 | 0.01270 |
| 10 | 55539 | -0.08956 | 55667 | 0.02220 | 55456 | -0.03100 |
| 11 | 72084 | -0.08600 | 71952 | 0.01200 | 71644 | 0.01360 |
| 12 | 72159 | -0.06100 | 72004 | -0.02800 | 71624 | 0.01300 |
| 13 | 72085 | -0.07700 | 71945 | -0.01300 | 71627 | 0.01590 |
| 14 | 72041 | -0.05200 | 71961 | -0.01600 | 71621 | -0.01800 |
| 15 | 72029 | -0.02700 | 71869 | 0.01240 | 71579 | 0.02310 |
| 16 | 83235 | -0.05600 | 83132 | -0.03100 | 83240 | 0.00860 |
| 17 | 83239 | -0.08500 | 83176 | -0.01800 | 83277 | -0.01000 |
| 18 | 83219 | -0.07100 | 83188 | -0.03700 | 83277 | 0.00034 |
| 19 | 83235 | -0.09100 | 83157 | 0.00659 | 83251 | 0.00498 |
| 20 | 83234 | -0.08000 | 83130 | -0.02500 | 83267 | 0.00365 |
| 21 | 98730 | -0.05700 | 98756 | -0.01885 | 98787 | 0.02510 |
| 22 | 98708 | -0.05000 | 98776 | -0.04500 | 98803 | -0.00700 |
| 23 | 98790 | -0.10270 | 98720 | -0.00330 | 99152 | -0.01300 |
| 24 | 98789 | -0.11987 | 98750 | -0.02700 | 99152 | 0.01280 |
| 25 | 98722 | -0.04300 | 98731 | -0.04400 | 99150 | 0.02620 |
| | | **** | Average Data | **** | | |
| 26 | 44471 | -0.06100 | 44530 | -0.00860 | 44473 | 0.00542 |
| 27 | 55553 | -0.03800 | 55685 | -0.00710 | 55472 | -0.00500 |
| 28 | 72080 | -0.06100 | 71946 | -0.00652 | 71619 | 0.00975 |
| 29 | 83232 | -0.07900 | 83157 | -0.02100 | 83263 | 0.00150 |
| 30 | 98748 | -0.07600 | 98747 | -0.02700 | 99009 | 0.00866 |
| | | **** | Standard Deviation | **** | | |
| 31 | 44471 | 0.02440 | 44530 | 0.05590 | 44473 | 0.01450 |
| 32 | 55553 | 0.04350 | 55685 | 0.06060 | 55472 | 0.03740 |
| 33 | 72080 | 0.02280 | 71946 | 0.01790 | 71619 | 0.01587 |
| 34 | 83232 | 0.01490 | 83157 | 0.01600 | 83263 | 0.00714 |
| 35 | 98748 | 0.03290 | 98747 | 0.01750 | 99009 | 0.01825 |

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