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PIPING ELBOW IRRECOVERABLE PRESSURE LOSS COEFFICIENTS FOR MODERATELY HIGH REYNOLDS NUMBERS

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ABSTRACT

Test data is described for three different piping elbows. These include 90° elbows with radii of curvature of 1.2 and 1.5, and a 45° elbow with a radius of curvature of 1.2. These radii of curvature are sufficiently sharp to cause significant irrecoverable pressure losses to occur. The variation in static wall pressure was measured upstream and downstream of each elbow plus spatially around the elbow itself. Irrecoverable loss coefficients over a range of flows were obtained and correlations for the data are provided. The testing extended the Reynolds number range of the currently existing data base in various handbooks (and other references available in the open literature) by over a factor of five. Comparisons of results to predictions from the correlations of prior studies are provided.

INTRODUCTION

In calculating the total pressure drop in coolant systems, the irrecoverable pressure drop in each fitting and component needs to be determined. It is this total pressure loss that establishes pumping power requirements for the system. Minimizing the errors associated with estimation of plant irrecoverable pressure drops, as well as reducing the pressure losses themselves, can lead to a reduction in required pumping power or an increased allocation of available pump pressure head to other system components, both of which result in reduced plant costs.

Prior to the testing to be described, the world's data base for piping elbows was limited and these were at relatively low Reynolds numbers ($<0.50 \times 10^6$). For example, less than a dozen data points were identified to exist for 45° elbows with a bend radius of curvature (r/D) less than 1.8, where irrecoverable loss effects start becoming significant. Data for 90° elbows was also found to be scarce with large inconsistencies between investigators.

Because of the lack of reliable data for predicting piping irrecoverable pressure losses, testing was performed over a Reynolds number range of 10^5 to slightly more than 2.5×10^6. This is approximately a factor of five increase in the Reynolds number relative to the prior data base. The test data was compared to predictions proposed by various handbooks and references. [Note: As a further example of the paucity of the previous data base, Crane (Reference (a)) which is one of the more widely used handbooks does not provide a correlation for 45° elbows.] Because the previous correlations are based on limited data and much lower Reynolds numbers, significant variations were found between these different sources and the data for this study. Comparisons of data to these commonly accepted correlations are provided in order to give designers an estimate of the degree of conservatism for applications up to a Reynolds number of 2.5×10^6.

TEST DESCRIPTION AND TYPICAL RESULTS

Three different elbow geometries were tested:

- 90° elbow with r/D = 1.5
- 45° elbow with r/D = 1.2
- 90° elbow with r/D = 1.2

at low pressure (<100 psig) and temperature (<120°F) conditions using acrylic elbows. Figure 1 shows the typical elbow geometry. The variation in static wall pressure was measured both upstream and downstream of the elbow plus spatially around the elbow itself. Pressure profiles through the test section were obtained by measuring the differential pressure between each pressure tap and a reference tap located five pipe diameters upstream of the elbow. Three inch copper tubing was used upstream and downstream of the elbow. The relative roughness values for the acrylic elbow and copper tubing are:

- Relative roughness (ϵ/D) for acrylic elbow = 4.2×10^{-6}
- Relative roughness (ϵ/D) for copper tubing = 2.0×10^{-5}

A typical axial pressure profile measured from the upstream piping through the downstream piping is shown by Figure 2 for the r/D = 1.2, 90° elbow at approximately 10^6 Reynolds number. The normalized pressure loss, C_p, is the ratio of the localized static wall pressure relative to the reference pressure divided by the average velocity head of the flow (based on average flow velocity, $\bar{V}$). This gives

$$C_p = (P - P_{ref})/\rho\bar{V}^2/2$$

For all three elbows, values of this parameter approached about 0.5 on outside of the bend and -1.5 on the inside of the bend. A sharper bend radius resulted in a slightly larger variation in C_p. After about one diameter upstream and downstream, the circumferential variation diminishes giving a fairly constant C_p value. As the flow progresses around the elbow, a secondary flow is established due to the circumferential pressure gradients. This results in a doublet shaped set of counter-rotating vortices being established which exit the elbow and progress into the downstream piping. C_p decays to a straight pipe pressure gradient (from normal straight pipe friction losses only) as these vortices dissipate with the downstream flow. The irrecoverable loss coefficient (K) for the particular elbow at the indicated Reynolds number is the offset between the straight line pipe pressure gradients of the piping sections upstream and downstream of the elbow (referred to as the inlet and outlet tangents). Very small burrs at the pressure tap intersection with the inner piping surface are believed to have caused the deviations from the linear pipe friction pressure drop at several positions upstream and downstream of the elbow (e.g., outer tap at the 50 inch position on Figure 2). The correlations derived from the variation in elbow irrecoverable loss coefficient data measured over the entire test range (from about 10^5 to 2.5×10^6 Reynolds number) are provided in Table 1 and shown by Figure 3 for all three elbows. Although the loss coefficients for the two 90° elbows are approximately the same at lower Reynolds numbers (e.g., 1×10^5) they become significantly different at the higher Reynolds numbers. For example, the loss coefficient is about 40% larger for the tighter curvature elbow at a Reynolds number of 2.5×10^6. The 45° elbow loss coefficient is about 8% less than the comparable radius of curvature 90° elbow at a Reynolds number of 10^5. However, this difference increases to about 65% at a Reynolds number of 2.5×10^6.

TABLE 1 PIPING ELBOW TEST RESULTS		
ELBOW GEOMETRY	**RECOMMENDED CORRELATION**	**CORRELATION COEFFICIENT**
90° with r/D = 1.5	$K = 5.10\ Re^{-0.252}$	0.99
45° with r/D = 1.2	$K = 6.32\ Re^{-0.278}$	0.91
90° with r/D = 1.2	$K = 1.49\ Re^{-0.145}$	0.96

Flow visualization studies were performed using both gas injection and dye injection to characterize the elbow flow field characteristics. It was found that the counter-rotating vortices and the recirculation region (due to flow separation) on the inside of the bend normally associated with an elbow downstream flow field were present and very similar for all three elbows tested. No flow separation region was identified on the outside of the bends.

SUMMARY AND CONCLUSIONS

Figure 4 shows a comparison of the test results (for 90° elbow with r/D = 1.2) to those proposed by various handbooks and references for this elbow geometry. These include Crane, Miller (BHRA), Idelchik, ESDU, Pigott and Ito in References (a) to (f), respectively. All the handbook correlations are based on limited data and Reynolds numbers less than about 5×10^5, which helps explain much of the large variation shown between these different sources.

For the 45° elbow, the Figure 4 type of comparison found that the handbook correlations have as much as a factor of two error at low Reynolds numbers (e.g., 10^5) and as much as 40% error at moderately high Reynolds number (e.g., 2.5×10^6). For the 90° elbows, discrepancies of the correlations with the test data are as large as 30%. At higher Reynolds numbers (e.g., 40×10^6) differences between the handbook predictions themselves are as large as a factor of two. Testing in this region requires using a high pressure, high fluid temperature loop which was beyond the scope of this study. The new test data provides designers with an estimate of the conservatism attained by using various commonly used design correlations for Reynolds numbers up to 2.5×10^6.

The detailed variation in pressure measured for the three elbows investigated provides valuable data to help qualify computational fluid dynamics (CFD) computer codes. Achieving good agreement with this data would provide confidence in the ability of the computer codes to predict piping elbow irrecoverable pressure loss coefficients up to a moderately high Reynolds number of 2.5×10^6.

REFERENCES

(a) Crane Technical Paper No. 410, Flow of Fluids Through Valves, Fittings, and Pipe, published by Crane Co., Chicago, 1988.

(b) D. S. Miller, Internal Flow Systems, (Second Edition), published by the British Hydromechanics Research Association, (Houston, Tx: Gulf Publishing Co.), 1990.

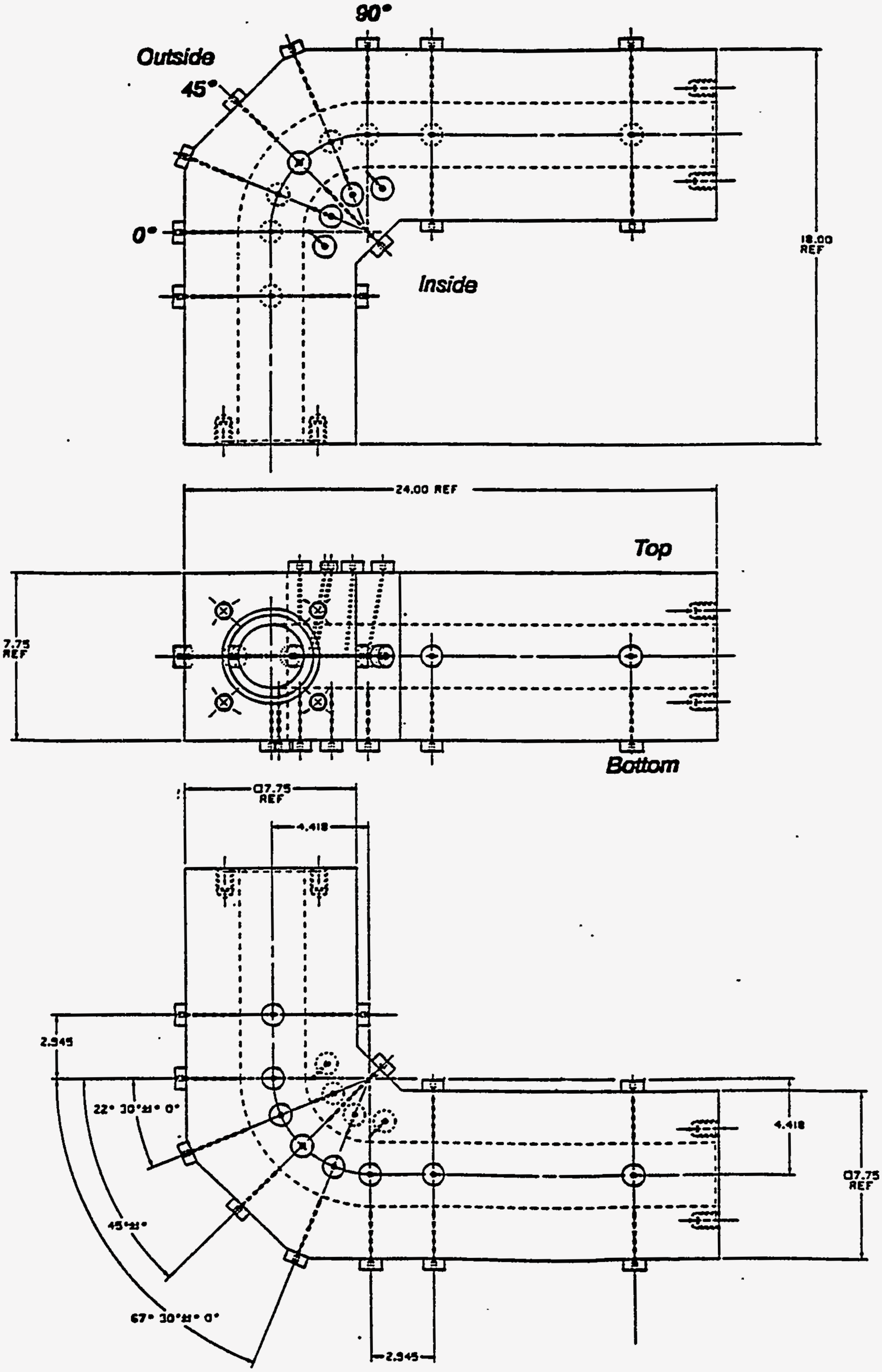
(c) I. E. Idelchik, Handbook of Hydraulic Resistance, (Second Edition, Revised and Augmented), published by Hemisphere, 1986.

(d) ESDU Engineering Sciences Data, Fluid Mechanics, Internal Flow, Vol. 2: Bends, Branches and Junctions, published by ESDU International, 1990.

(e) R. J. S. Pigott, "Losses in Pipe and Fittings," Trans. ASME, Vol. 79, pp. 1767-1783, 1957.

(f) H. Ito, "Pressure Losses in Smooth Pipe Bends," Trans. ASME, J. Basic Eng., Vol. 82, pp. 131-143, March 1960.

FIGURE 1: TYPICAL ACRYLIC ELBOW GEOMETRY



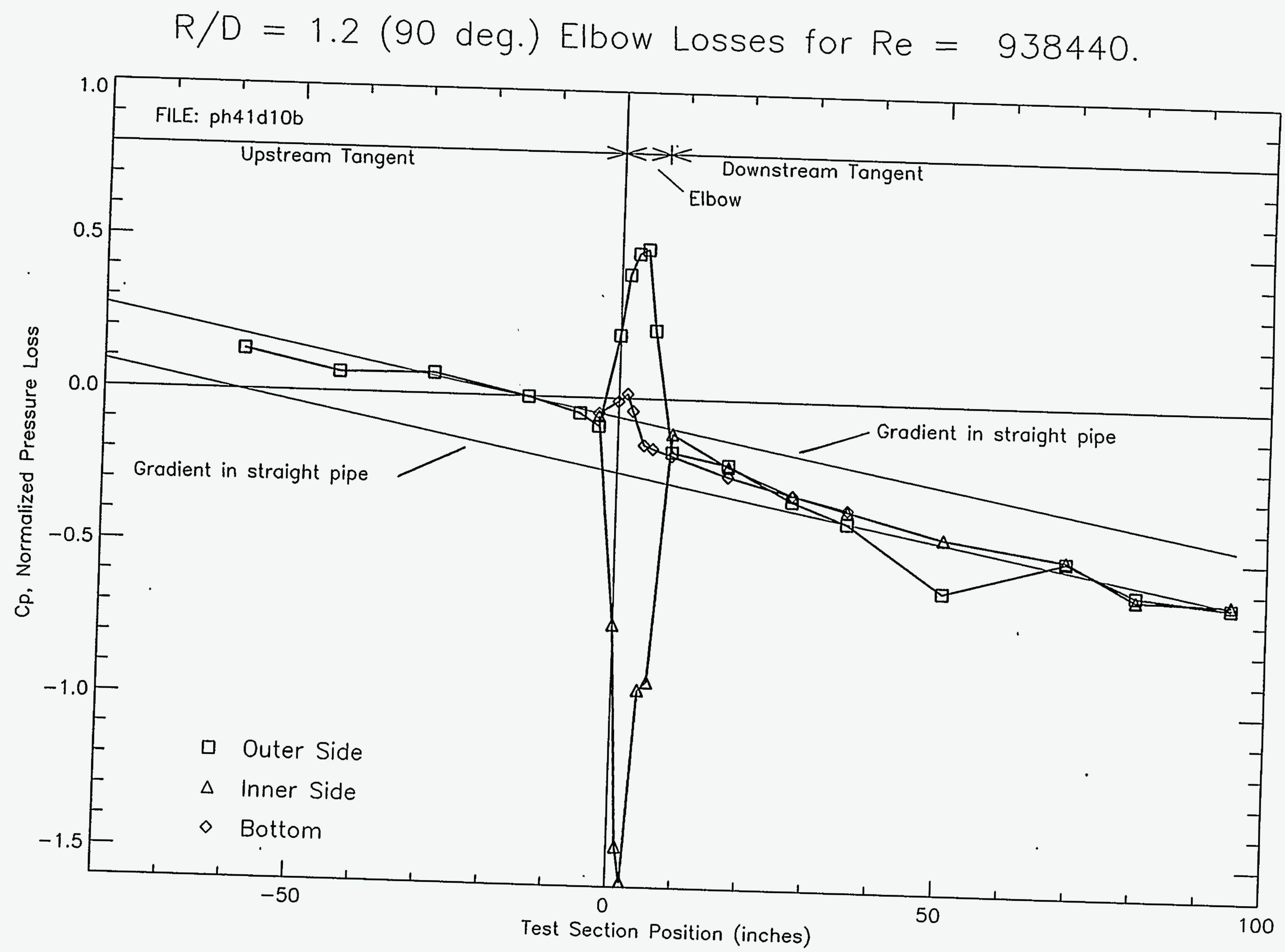

R/D = 1.2 (90 deg.) Elbow Losses for Re = 938440.
FILE: ph41d10b
Upstream Tangent
Elbow
Downstream Tangent
Gradient in straight pipe
Gradient in straight pipe
Cp, Normalized Pressure Loss
1.0
0.5
0.0
−0.5
−1.0
−1.5
−50
0
50
100
Test Section Position (inches)
Outer Side
Inner Side
Bottom

FIGURE 2

FIGURE 3

Summary of Elbow Irrecoverable Loss Coefficient Test Results as a Function of Reynolds Number

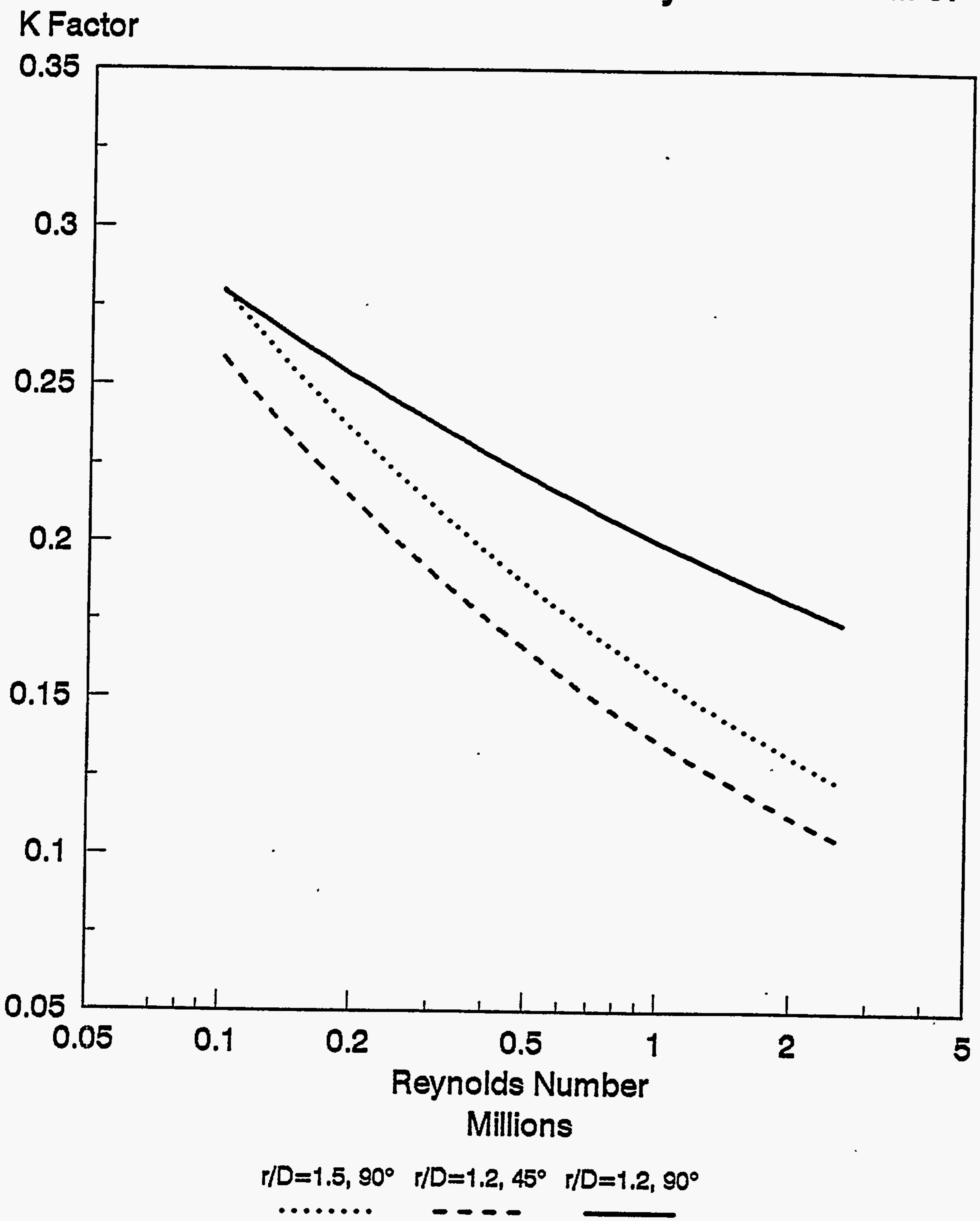


FIGURE 4

Comparison of Irrecoverable Loss Coefficient Data for r/D=1.2, 90° Elbow to Other Sources