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Effect of Pipe Roughness on Orifice Flow Measurement

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Abstract

Flow measurement with orifice flowmeters is simple in concept and can be accurate, but as has been demonstrated in flow measurement test facilities can also result in large errors if any of the significant parameters are not controlled. Many of these parameters are well known and particular care is taken to ensure that they do not cause measurement errors. Others are more subtle and not so easily detected or controlled. One such parameter is the surface finish of the pipe immediately upstream of the orifice plate. Results of an experimental investigation into the effects of this pipe roughness on the orifice discharge coefficient are presented, along with a review of some of the pertinent literature. Measurement errors of approximately 1 percent can result from using meter tubes that are too rough but still within the specification of the standards.

Key words: air; experimental; flow measurement; nitrogen gas; orifice discharge coefficient; orifice meter; roughness; surface finish; water.

Introduction

In many experimental programs designed to determine discharge coefficients for orifice flow measurements, several important parameters that affect the results have been identified. One parameter is the surface finish or roughness of the pipe upstream of the orifice plate. Both the U.S. [1] and ISO [2] standards on orifice flow measurement have tolerances for the pipe roughness, but they are different from one another and neither adequately defines the correct allowable roughness values for all permissible beta ratios (orifice diameter/pipe diameter). Surface finish is not a simple parameter to quantify. For example, ten ways to define the surface texture are tabulated in the ANSI standard [3], and published reports do not always state which roughness value is being used. Reference 3 lists only one method under the United States. That method is the arithmetic average roughness symbolized by R_a. The maximum peak-to-valley roughness, R_y, and the ten-point height method, R_z, along with R_a, are listed under ISO. AA and CLA were formerly used to symbolize the arithmetic average and are equivalent to the R_a values. RMS, or root-mean-square, roughness values are not commonly used and, in fact, require more specialized measuring equipment than is normally available. It is suspected that many of the references to RMS values should be R_a values. The only time they are equivalent is when the surface finish is sinusoidal. A more complete description of surface finish terminology is included in a later section of this report.

During the past several years, many experimental programs have investigated orifice flow measurement. Those programs were carried out in many different laboratories throughout the world. There has been considerable duplication of effort in that work and also with similar work that was completed many years ago. Some of the work has been affected by pipe roughness and has required discarding large amounts of data. Many of the problems caused by roughness that were faced in earlier work are still being repeated today largely because the previously obtained data were not reported, not reported clearly, or could not be quantified because of a confounding effect from another parameter. There may be several reasons for the lack of adequate reporting, but in an effort to prevent unintended duplication in the future an attempt is made in this report to summarize the findings of the previous work and report the results of a recently completed experimental program designed to quantify the upstream pipe roughness effect.

The experimental program was a National Institute of Standards and Technology (NIST) project under sponsorship of the Gas Research Institute (GRI) to systematically investigate the effects of upstream pipe roughness on the orifice discharge coefficient. In this program water, air, and nitrogen gas were the test fluids and data were taken on three orifice meter sizes: 3, 4, and 6 inch. Data were collected on four orifice beta ratios (ratio of orifice to pipe diameter) and three upstream pipe sections for each meter size. Each upstream section had a different surface finish. The data using water were obtained on the NIST water flow facility in Gaithersburg, Maryland (NIST-G). The data using air were taken on a commercial flow facility and the data using nitrogen gas were taken on the NIST facility in Boulder, Colorado (NIST-B) [4].

Literature Review

This review is not intended to be all inclusive. Rather, its purpose is to indicate that the surface roughness problem has been recognized for a long time and that there is a consistent pattern, within the literature, that clearly shows the surface roughness specification in the flow measurement standards need some modification if flow measurement errors are to be avoided.

McNulty and Spencer [5] carried out some roughness experiments with a 4-inch orifice meter which also included a variation in the diameter of the orifice plate holder. This caused a step change in the pipe diameter in close proximity to the orifice plate. The experiments were carried out using three different pipes. They described one of their pipes as "'rough,' i.e., the paint work on the inside of the pipe had broken down, exposing the metal in parts." Another pipe "was machined for a length of approximately 6 diameters upstream and downstream, and repainted with an anti-corrosion paint." The third pipe was "chromium-plated internally after honing and gave CLA readings of about 10 micro inches." No roughness values were reported for the two non-honed pipes; they were only referred to as rough and smooth. Four orifice plates with beta ratios of 0.4, 0.6, 0.74, and 0.8 were used.

The data reported in [5] are difficult to categorize with respect to roughness because close to the orifice plate they had variable disturbances that were not duplicated in all the different pipes. The authors concluded that the increase in coefficient caused by an increase in the orifice plate carrier diameter "was not so marked when the upstream pipe was very smooth." The data in this report could not be separated sufficiently to yield a magnitude for a change in orifice discharge coefficient resulting from pipe roughness effects alone.

In the late 1950's, the American Gas Association (A.G.A.) sponsored a study of the effect of pipe roughness on orifice meter accuracy. Experimental work was conducted with water at the Naval Boiler and Turbine Laboratory and with natural gas at a natural gas company. This study consisted of testing both 2- and 4-inch flowmeters [6,7]. Originally, the 2-inch tests were to include five meter tubes with varying degrees of roughness and five orifice plates with beta ratios from 0.36 to 0.75 [6]. The first phase of the project was to use water as the test fluid and the second phase was to use natural gas.

After the first water test "...both tubes A and C had become rusted in varying degrees." Therefore, the project had to be revised. The revised program consisted of only two meter tubes and three beta ratio orifice plates (0.5, 0.6, and 0.75). One of the meter tubes was constructed of stainless steel to control the rusting and was honed to a surface finish of 1.3 μm (50 μin). This meter tube served as the "reference meter." The other tube was one of the original meter tubes that had not been tested in water and had a surface finish of 10 μm (400 μin). Special care was taken to control the rusting of this meter tube during the test program. It is assumed that the reported roughness values were R_a values.

All tests were run at nearly the same flow rate which produced an orifice differential pressure of approximately 22 kPa (90 in H_2O) and pipe Reynolds numbers as shown in table 1. A very consistent correlation of increasing discharge coefficient with increasing beta ratio and increasing pipe roughness was observed. Table 1 lists the averages of the observations published in [6]. In the table, the symbol C represents the discharge coefficient and the subscripts R and S refer to the rough and smooth pipes. Based on these results, the authors recommended that additional tests be run with a 4-inch meter with beta ratios of 0.5 and 0.6.

Table 1
Average observed changes in the discharge coefficient
in a 2-inch orifice meter attributable to pipe roughness [6]

Beta Ratio	Test Fluid	Pipe Reynolds Number	$\frac{C_R - C_S}{C_S} \cdot 100$
0.5	water	6.3×10^4	0.1
0.5	gas	4.15×10^5	0.1
0.6	water	9.3×10^4	0.2
0.6	gas	6.24×10^5	0.5
0.75	water	1.74×10^5	0.5
0.75	gas	1.09×10^6	1.0

Test results from the A.G.A. project using the 4-inch meters were also reported by Bean and Murdock [7]. Five seamless meter tubes were used for these tests with one reserved as a reference meter and the other four used to provide variations in roughness. Using orifice plates with beta ratios of 0.5 and 0.6, base data were obtained on all five meter tubes, which were characterized as "normal mill surface."

Roughness was determined on the original 4-inch meter tubes by cutting a small section out of the meter tube at the location where the orifice flanges were to be attached. Measurements were made on this small section using a profilometer and the values ranged from 2.3 to 4.3 μm (90 to 170 μin) for all five meter tubes. It is assumed that these roughness values are the arithmetic average values, R_a.

After the base data tests were completed, two of the meter tubes were honed and retested. The roughness of the honed tubes was measured but this time the measurements were made on the actual meter tubes rather than a cut-out sample. The range of roughness varied from 0.5 to 2.3 μm (20 to 130 μin) for these honed tubes and the average of all the measurements was 1.0 to 1.2 μm (41 to 47 μin).

This test program was carried out at a natural gas company using natural gas as the test fluid. All tests were run at nearly the same flow rate which produced an orifice differential pressure of approximately 22 kPa (90 in H_2O) and pipe Reynolds numbers between 1 and 2×10^6. The authors reported that the "results conclusively indicated that tubes can be honed without affecting their accuracy." As will be discussed in a later section of this report, the range of beta ratios, roughness, and Reynolds numbers was probably not large enough in these 4-inch tests to show the effect of roughness on the discharge coefficient.

Clark and Stephens [8] investigated the effect of roughness in 12-, 6-, and 3-inch pipes using air, and in a 3-inch pipe using water. Four orifice beta ratios were used ranging from 0.50 to 0.71. They produced different values of roughness by lining the pipes. The linings included wallpaper, sand particles, dried peas, and glass spheres. The length of the rough section was generally 12 diameters and always left a narrow (1.3-1.9 cm (1/2-3/4 in)) strip of smooth pipe next to the orifice plate. This method of producing roughness simulated very rough pipe.

Results from these tests are presented as combined roughness and pipe diameter change; that is, pipe diameters were measured before adding the rough linings. Differences in discharge coefficients of several percent were measured for all pipe sizes. The observed differences are much larger than have been reported by any other known source.

Downstream pipe roughness was also studied by Clark and Stevens and found to be insignificant compared to the upstream pipe roughness effect. Cleaning of the upstream pipe was also investigated for all pipe sizes and the stated conclusion was "...that cleaning a rough upstream pipe adjacent to an orifice plate for a relatively short distance reduces errors which may be otherwise very considerable to within known small limits." A table given in the report lists recommended upstream clean pipe requirements to get roughness errors not exceeding a stated value. Since the results reported in this paper are rather unique (that is, the results are confounded by the change in pipe diameter; thus the errors are very large

and the effect of roughness not easily separated), the reader is referred to the original paper for further information.

A three-facility interlaboratory test of a 200 mm orifice meter that included an investigation of the effect of pipe roughness was reported by Spencer, Calame, and Singer [9]. These tests were all run with water as the test fluid and conclusively showed that the discharge coefficient for a 0.8 beta ratio plate increased by 1.6% in rough pipe compared to smooth pipe at a Reynolds number of 1.2×10^6. Included in these tests was a systematic elimination of other possible causes of the difference in the discharge coefficient.

Two values of roughness were included in the tests reported in [9]. One, referred to as rough, was actually a commercial pipe; the other was a pipe specially selected for roundness and smoothness. A friction factor was determined by measuring pressure drop over a length of pipe, and then a relative roughness was calculated. The value thus calculated for the "rough" pipe was such that it would be "...classed as a relatively smooth pipe." Similar measurements were made on the smooth pipe, and it was "...significantly smoother than..." the rough pipe. The actual values of friction factor for the two pipes were given as 0.018 for the rough and 0.011 for the smooth pipe.

Reader-Harris and Keegans [10] have included pipe roughness as a parameter in their computational work and have compared computed discharge coefficients with some experimentally determined values. In general, the comparisons are quite good and show a significant roughness effect. In addition, they stated a belief that the experimentally determined dependence of the discharge coefficient on Reynolds number to the -0.75 power is caused by "...using pipes that are insufficiently smooth."

Sheikholeslami and Patel [11] have modeled flow through an orifice meter and have included roughness as one of the parameters. At a pipe Reynolds number of 4×10^6, they calculated an increase in discharge coefficient of 0.66% for an orifice beta ratio of 0.4 in an 8-inch flowmeter when the relative roughness was increased from 0.000 01 to 0.0001. They found no experimental data that matched their range of variables. An additional computation was made using a beta ratio of 0.6, a pipe Reynolds number of 10^6, and a relative roughness of 0.005 for which they did have some experimental data. In that case the computed increase in discharge coefficient was about 0.9% and the experimental value was 1%. Their model shows that the rough pipe decreases the upstream pressure and thereby reduces the orifice pressure drop and causes the discharge coefficient to increase.

In an EEC orifice meter project in which a 100 and a 250 mm orifice meter were tested in a number of flow facilities in Europe there was at least one case when the 250 mm pipe became rusty [12]. Tests were run at a water flow facility on the pipe in the rusty condition and then cleaned and tested again. Figure 1 is a plot of the data from [12] and clearly shows the difference between those two tests. At the maximum Reynolds number, the difference in the discharge coefficient exceeds 1%. Unfortunately, there was no indication of surface finish given for either the rusty or the clean pipe.

One part of a previous (1985) GRI/NIST flow measurement project involved determining the comparisons of the data obtained in nitrogen gas taken at NIST-B and in water taken at NIST-G. A 3-inch carbon steel orifice meter was tested in both locations with either 5 or 6 different beta ratio orifice plates. At beta ratios less than 0.57 the comparisons were quite good, but with increasing beta ratios the agreement got progressively worse, and the water discharge coefficient was larger than that determined with nitrogen gas.

A second 3-inch orifice meter was constructed of stainless steel and was also tested in water at NIST-G. The discharge coefficients determined with this flowmeter compared quite well with those determined with the carbon steel meter tube, except for beta ratios of 0.57 and larger. As the beta ratio increased, the difference between the results from the two meter tubes increased. At the largest Reynolds number, with the 0.73 beta ratio plate, the difference between the discharge coefficients exceeded 1%. Again, the carbon steel discharge coefficients were larger. The effect observed in these tests was reported for three orifice plates (beta = 0.37, 0.65, and 0.73) in [13], and clearly showed that there was a roughness effect for the two larger beta ratio plates.

The cause of the differences observed in those tests was a difference in roughness in the meter tubes. Between the time the carbon steel meter tube was tested in Boulder and Gaithersburg it had become very rusty. No roughness values are available for the rusty pipe, but a visual inspection revealed that it had become quite rough. The stainless steel meter tube, on the other hand, had an R_a surface finish of 2.3 μm (90 μin).

All of the test results listed above are consistent in the sense that they reported an increase in discharge coefficient with increased pipe roughness for large beta ratio orifice plates. There are some inconsistencies in the reporting and the measurement of the surface finishes, however. Since surface roughness can be such an important parameter, and its measurement not a trivial procedure, some of the measurement techniques are described in the next section.

Surface Finish Measurement

Conceptually, one of the simplest methods used for quantifying surface finish is the comparative technique. In this method, surfaces of known roughness are successively visually compared to the unknown surface and by a process of elimination an estimate is made of the unknown roughness. Comparisons can be difficult because a surface's preparation has a large effect on its appearance. The method is subjective and consequently operator dependent, which makes the results unreliable.

Another method of roughness determination calculates the relative roughness, k/D, from pressure drop measurements over a relatively long pipe. First, the friction factor must be calculated from equation (1) and then the relative roughness can be calculated using the Colbrook [14] equation (2). This method gives some average value of roughness over the length of the pipe.

$$\lambda = (D2\Delta p)/(L\rho v^2) \tag{1}$$

$$\frac{1}{\sqrt{\lambda}} = -2\log\left[\frac{k}{3.7D} + \frac{2.51}{R_D\sqrt{\lambda}}\right] \tag{2}$$

where:

λ = friction factor
D = pipe diameter
Δp = pressure drop
L = pipe length
ρ = fluid density
v = average fluid velocity
R_D = pipe Reynolds number
k = equivalent roughness

Relatively short pipes upstream of the orifice plate control the major portion of the roughness effect, therefore, this averaging method could be unsuitable for nonuniformly rough pipe.

A third method of determination is to measure the roughness directly. A variety of instruments are available for making such measurements, both in a laboratory and in the field. Using this method of roughness determination gives a more localized value, but making measurements very far from the pipe ends can be difficult, especially in small pipes. Using this method, it is possible to obtain different roughness values from a single pipe and, thereby, better define the localized and perhaps the controlling surface.

No matter what measurement method is used, it is imperative that the values determined be presented unambiguously. Since surface finish can be specified in different ways, a description of the method used should be stated. The method used for the tests reported in the following sections of this report was the direct measurement with an instrument that gave either the common R_a value or the R_z (ten-point height) value. These measurements are made by moving a stylus over the surface to be measured; the instrument then proportions the areas of the peaks and the valleys and establishes a center line such that the positive areas and the negative areas are equal. It then determines the deviation from the center line. The absolute value of the deviations are added and the average of these deviations is given as R_a. This value is the absolute mean deviation, not the root-mean-square value, and appears to be the value referred to in ANSI/API 2530 [1]. The surface roughness used in the Moody [15] chart to determine relative roughness of pipes for pressure loss calculations is the average of the valley bottoms to the peak tops (peak-to-valley) over the measured sample length and appears to be the value referred to in ISO 5167 [2]. Figure 2 shows a pictorial representation of the three surface finishes symbolized as R_a, R_y, and R_z.

All roughness values listed on figures 3-21 and the tables in the appendix are R_a values. In table 2 both R_a and R_z values are given but all other references to roughness measurements in the experimental portion of this report refer only to R_a values.

Another parameter, cut-off length, is also required to define the surface finish measurement. The cut-off length is the length of the trace used to determine the center line and the calculated area. The shorter the cut-off, the more likely that the finish value will exclude longer irregularities, such as a long wave or surface curvature. The cut-off used for the surface finish measurements reported here was 2.5 mm (0.10 in). The instrument averaged five cut-off lengths to establish each reading.

Table 2
Measured roughness values for all the meter tubes used in this study

Meter Size	Smooth				Intermediate				Rough			
	R_a		R_z		R_a		R_z		R_a		R_z	
in	μm	μin	μm	μin	μm	μin	μm	μin	μm	μin	μm	μin
3	0.89	35	6.1	240	4.1	160	27.7	1090	7.6	300	44.7	1760
4	0.76	30	4.6	180	3.8	150	21.8	860	6.9	270	46.5	1830
6	2.80	110	18.7	735	5.1	200	32.0	1260	8.9	350	56.5	2225

Test Results and Discussion

The effects of upstream pipe roughness on the orifice discharge coefficient were investigated with water, air, and nitrogen gas as the test fluids. Data were taken in three orifice meter sizes, 3, 4, and 6 inch. Four beta ratios and three upstream surface finishes were investigated with each meter size. The data using water were taken at the NIST-G water flow facility. The data taken in air were taken at a commercial flow facility and the data taken in nitrogen gas were taken at the NIST-B facility.

In the tests run at NIST-B and the commercial facility it was not possible to determine the orifice discharge coefficient directly. All test results yield the product of the discharge coefficient and the expansion factor. The expansion factor was calculated according to ANSI/API 2530 [1] and used to calculate the discharge coefficient. In the water facility at NIST-G this was not necessary because the expansion factor was equal to 1.

The orifice meters used for the test of surface finish effects were all constructed similarly. They consisted of an approach section, an upstream section, and a downstream section, as shown in figure 3. All meters were made of stainless steel so that the surface would not deteriorate during the test program. They were all made with only flange tappings. Table 3 lists the lengths of the meter sections.

Table 3
Orifice meter tube lengths

Meter Size	Approach			Upstream			Downstream		
	cm	in	$\frac{L}{D}$	cm	in	$\frac{L}{D}$	cm	in	$\frac{L}{D}$
3 in	266	105	34	67	26.4	9	136	53.7	17
4 in	355	140	34	116	45.7	11	167	65.7	16
6 in	531	209	34	136	53.6	9	228	89.8	15

An oversized Sprenkle flow conditioner located at the upstream end of the approach section removed any flow disturbances that may have been present. Each meter included three upstream sections, each of different surface roughness. The surface roughness ranged from 0.76 to 8.9 μm (30 to 350 μin). The surfaces were prepared by honing the entire length of the upstream section. The primary pattern resulting from the honing was circular and was consistent throughout the length of the upstream section.

The surface roughness was measured with a profilometer at three radial locations 20 cm (8 in) from the upstream end, 20 cm (8 in) upstream of the pressure tap and in the plane of the pressure tap. The surface finishes determined for the upstream sections are given in table 2.

The test plan for determining the effects of the meter tube roughness on the orifice discharge coefficient was randomized to determine any day-to-day effects, as well as the effects of changing orifice plates. Data for all the tests are tabulated in the appendix.

The 3-inch meter was tested with water at NIST-G and with nitrogen gas at NIST-B. The tests using water were made with orifice plates of 0.57, 0.65, and 0.73 beta ratios. The tests using nitrogen gas were made with orifice plates of 0.49, 0.57, 0.65, and 0.73 beta ratios.

Some typical results obtained with the 0.65 beta ratio plate in the 3-inch meter are shown in figures 4, 5, and 6, where each point represents a single independent data point. Figures 7 through 10 show a comparison of the mean of the orifice discharge coefficients for the three surface finishes and four beta ratios. These comparison graphs show that the orifice discharge coefficient increases with surface roughness and is dependent on Reynolds number and beta ratio. In this 3-inch meter, the maximum observed increase in orifice discharge coefficient caused by roughness is 1% at a beta ratio of 0.73 and a Reynolds number of 2×10^6. Only the 0.49 beta ratio plate was not affected by the pipe surface roughness.

The 4-inch meter was also tested with water at NIST-G and with nitrogen gas at NIST-B. The tests using water were made with the orifice plates of 0.55, 0.67, and 0.73 beta ratios. The tests using nitrogen gas were made with the orifice plates of 0.43, 0.55, 0.67, and 0.73 beta ratios.

A comparison of the changes in the orifice discharge coefficient in the three surface finishes and the four beta ratios are shown in figures 11 through 14. Each data point on these figures represents the average of the orifice discharge coefficient and the Reynolds number at approximately the same Reynolds numbers. As with the 3-inch meter data, the graphs show a trend of increasing orifice discharge coefficient as the surface roughness, Reynolds number, and beta ratio increase. The change in the orifice discharge coefficient caused by roughness is 1% at a beta ratio of 0.73 and a Reynolds number of 1.7×10^6. Only the 0.43 beta ratio plate was not affected by the pipe roughness.

The 6-inch meter was tested with water at NIST-G and with air at a commercial flow facility. The tests with water used orifice plates with the beta ratios of 0.49, 0.66, and 0.74. The test with air used orifice plates with beta ratios of 0.57, 0.66, and 0.74.

Comparisons of the change in orifice discharge coefficients are presented in figures 15 through 18. Each data point on these graphs represents the average of the orifice discharge coefficient and the Reynolds number at approximately the same Reynolds numbers. The trends of the data are the same as with the 3- and 4-inch meters; however, for the 6-inch meter, the data cover a much higher Reynolds number range and the change in discharge coefficient continues to show an increase, especially at a beta ratio of 0.74. The change is 1.5% between the surface finish of 2.8 μm (110 μin) and 8.9 μm (350 μin) at the maximum Reynolds number. Only the 0.49 beta ratio plate was not affected by the pipe roughness.

Two data sets were omitted from the graphs, one set in the 4-inch data identified as 45051387-1 through -9 (table 36) and one set in the 3-inch data identified as 34042987-1 through -9 (table 5). Neither of these sets of data fits the other data sets run at the same conditions nor do they fit the data trends of other data sets. No cause for the differences was identified but it can be speculated that it was a badly positioned plate. The data are included in the tables in case they represent an anomaly of some real but unexplained cause.

The data show good agreement among the three laboratories. The 6-inch water and air data match reasonably well where they meet. Also, the 4-inch water data match with the

gaseous nitrogen data where they meet. The largest mismatch between the water data and the gas data is with the 0.65 beta ratio plate in the 3-inch meter where the difference is approximately 0.4%. The interlaboratory agreement is especially significant since the data meet where the differential pressure across the orifice plate may be as much as 185 kPa (750 in H_2O) in water and as little as 2.5 kPa (10 in H_2O) in the gases.

These test results indicate that for beta ratios of 0.55 or larger, the current specifications of surface roughness in the standards [1,2] are inadequate to assure that the orifice discharge coefficient stays within the specified tolerance.

A summary of the experimental test results is given in table 4. The change in discharge coefficient that is shown may not represent the maximum effect; It may have been larger at higher Reynolds numbers. Even at the Reynolds numbers presented here, however, the magnitude of the change clearly shows that control of the roughness is necessary to ensure accurate flow measurement. In the table the symbol C represents the discharge coefficient and the subscripts R, I, and S refer to the rough, intermediate, and smooth pipe.

Table 4
Summary of experimental results

Meter Size (in)	Beta Ratio	Test Fluid	Pipe Reynolds Number	$\frac{C_I - C_S}{C_S} \cdot 100$	$\frac{C_R - C_S}{C_S} \cdot 100$
3	0.49	N_2 gas	1.4×10^6	<0.1	0.1
3	0.57	water	3.9×10^5	<0.1	<0.1
3	0.57	N_2 gas	1.8×10^6	0.4	0.6
3	0.65	water	5.3×10^5	<0.1	0.2
3	0.65	N_2 gas	2.0×10^6	0.4	0.8
3	0.73	water	7.0×10^5	<0.1	0.3
3	0.73	N_2 gas	2.1×10^6	<0.1	1.0
4	0.43	N_2 gas	1.3×10^6	<0.1	<0.1
4	0.55	water	4.7×10^5	<0.1	0.1
4	0.55	N_2 gas	1.6×10^6	0.2	0.4
4	0.67	water	7.5×10^5	0.1	0.4
4	0.67	N_2 gas	1.6×10^6	0.3	0.5
4	0.73	water	9.4×10^5	0.2	0.5
4	0.73	N_2 gas	1.7×10^6	0.2	1.0
6	0.49	water	4.5×10^5	<0.1	<0.1
6	0.57	air	7.0×10^6	0.2	0.5
6	0.66	water	1.0×10^6	0.1	0.4
6	0.66	air	11.8×10^6	0.2	1.0
6	0.74	water	1.4×10^6	0.1	0.8
6	0.74	air	12.3×10^6	0.3	1.5

An experimental study of the required upstream length of smooth pipe to eliminate the roughness effects was also included in this program. This study used the 4-inch flowmeter and consisted of honing the roughest upstream pipe section to an R_a surface finish of 1.3 μm (50 μin), first two and then four diameters upstream of the orifice plate flange face.

The first tests, with the upstream section honed two pipe diameters upstream from the orifice plate flange face, were run with orifice beta ratios of 0.43, 0.55, 0.67, and 0.73. The data from these tests are plotted in figures 19 through 22. As expected, there was no

difference in the orifice coefficients for the 0.43 beta ratio plate and only a small effect for the 0.55 beta ratio plate. For beta ratios of 0.67 and 0.73, the orifice coefficient change was inconsistent. The results with the 0.67 beta ratio plate were nearly the same as when the upstream section was all rough and the results with the 0.73 beta ratio plate changed significantly. In fact, the 0.73 beta ratio coefficient almost equals the value obtained with the smooth pipe.

The upstream section was then honed for four pipe diameters upstream of the orifice plate flange. Tests were run with the 0.67 and the 0.73 beta ratio plates. These data are included in figures 21 and 22. There was no change between these results and the results obtained when the pipe was only honed for two pipe diameters, nor were the coefficients the same as with the smooth pipe.

The figures show the data obtained with the pipe honed for both two and four pipe diameters upstream from the orifice plate. Data with the smooth upstream section and the rough upstream section are also shown and are indicated by the solid and dashed lines, respectively. The first impression is that the rough upstream meter tube may just result in different orifice coefficients even if it were honed for its entire length. However, the data for beta ratios of 0.43 and 0.55, which are shown in figures 19 and 20, indicate that the data are the same for the two meter tubes. These results show that more than four pipe diameters of smooth pipe are required to control the discharge coefficient.

Conclusions

A consistent pattern in both the published literature and in the new experimental data shows that the effect of upstream pipe roughness on the orifice discharge coefficient is related to the pipe's surface finish, the orifice beta ratio, and the pipe Reynolds number. The largest change in discharge coefficient occurs at the highest beta ratio and the largest Reynolds numbers. The published literature does not give enough information to indicate the overall relationships, but the trends are consistent with the new experimental data. With the new data it is possible to draw some definite conclusions about the effect of roughness on meter sizes through 6 inches, and figure 1 shows that the effect is also present in 10-inch flowmeters.

The following conclusions are drawn from the new experimental data generated in this program. These conclusions are based on the range of parameters tested and may require modification at other values of the parameters. For example, the change in discharge coefficient may be larger at higher Reynolds numbers.

1. For orifice beta ratios less than 0.5, there is no statistically significant effect on the discharge coefficient caused by roughness within the present ANSI/API 2530 specification [1].

2. For R_a roughness values less than 3.8 μm (150 μin) the effect on the discharge coefficient caused by roughness is less than 0.5% for any beta ratio less than 0.75.

3. For orifice beta ratios $\geq$ 0.55 and R_a roughness values $\geq$ 3.8 μm (150 μin), a statistically significant roughness effect on the discharge coefficient does exist.

4. For an orifice beta ratio of 0.73 and an approximate R_a roughness value of 7.6 μm (300 μin) the roughness effect on the discharge coefficient can exceed 1%.

5. The surface finish tolerance in both standards [1,2] is not adequate to prevent flow measurement errors that can exceed 1%.

6. Honing the orifice meter for two or four pipe diameters upstream of the orifice plate to a roughness of 1.3 μm (50 μin) will not remove all of the effects of upstream pipe roughness apparent with beta ratios of 0.67 and higher.

Recommendations

Based on the findings in the experimental program and a review of the published literature, the following recommendations are suggested as necessary changes to the existing orifice meter standards.

1. Orifice beta ratios should not exceed 0.5 for flow measurement installations in which the pipe roughness of the upstream pipe is not known.

2. The arithmetic average roughness, R_a, should not exceed 3.8-5.1 μm (150-200 μin) if orifice beta ratios larger than 0.55 will be used.

3. Roughness tolerances should continue to be specified on an absolute, not a relative, roughness basis.

At this time, the required length of smooth upstream pipe is not defined well enough to make a recommendation in this area. The experimental results with the 4-inch meter show that four diameters or less are not sufficient for returning the meter to the equivalent of a long smooth upstream section for all beta ratios. Four diameters does appear sufficient for all but the largest tested beta ratios. Additional work in this area needs to be completed before definitive recommendations can be made.

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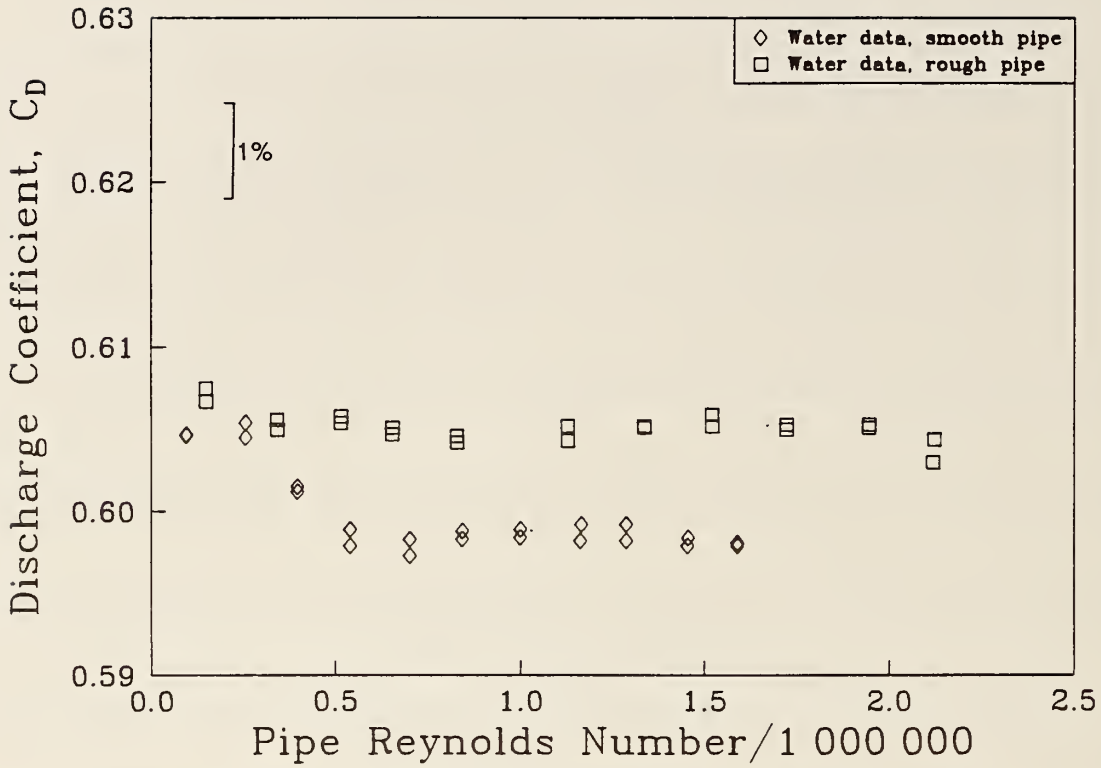
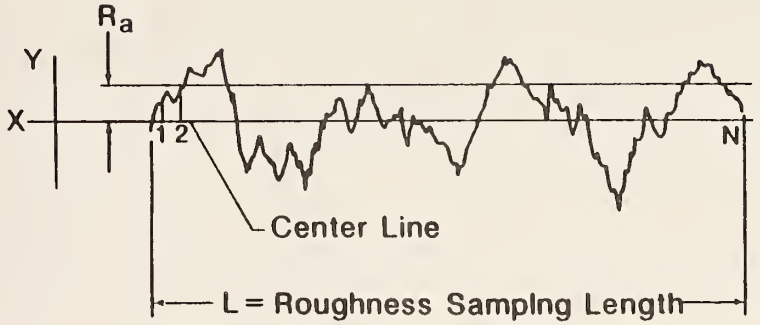
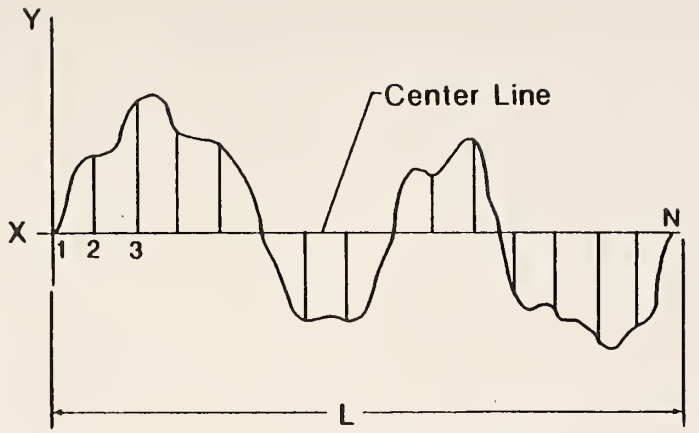


Figure 1. Effect of rusty pipe on the orifice discharge coefficient with a 0.75 beta ratio plate in a 250 mm orifice meter [12].



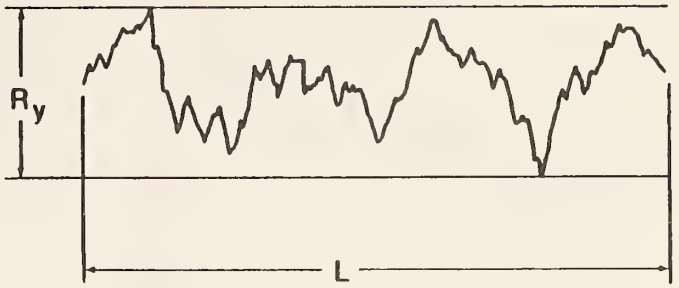
$$R_a = \frac{1}{L}\int_{x=0}^{x=L} |y|\,dx$$

(a)

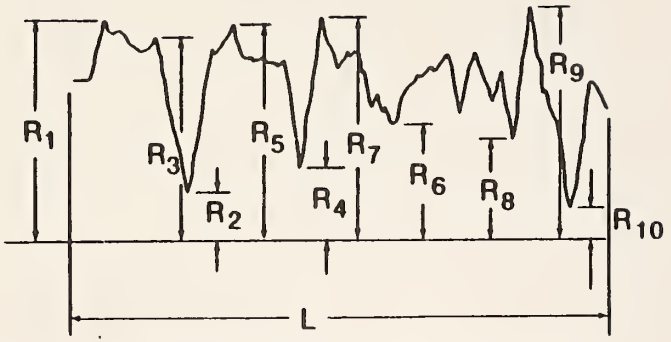


$$R_a \text{ (approx)} = \frac{y_1+y_2+y_3\cdots y_N}{N}$$

(b)



(c)



$$R_z = \frac{(R_1+R_3+R_5+R_7+R_9)-(R_2+R_4+R_6+R_8+R_{10})}{5}$$

(d)

Figure 2. Surface finish representation.

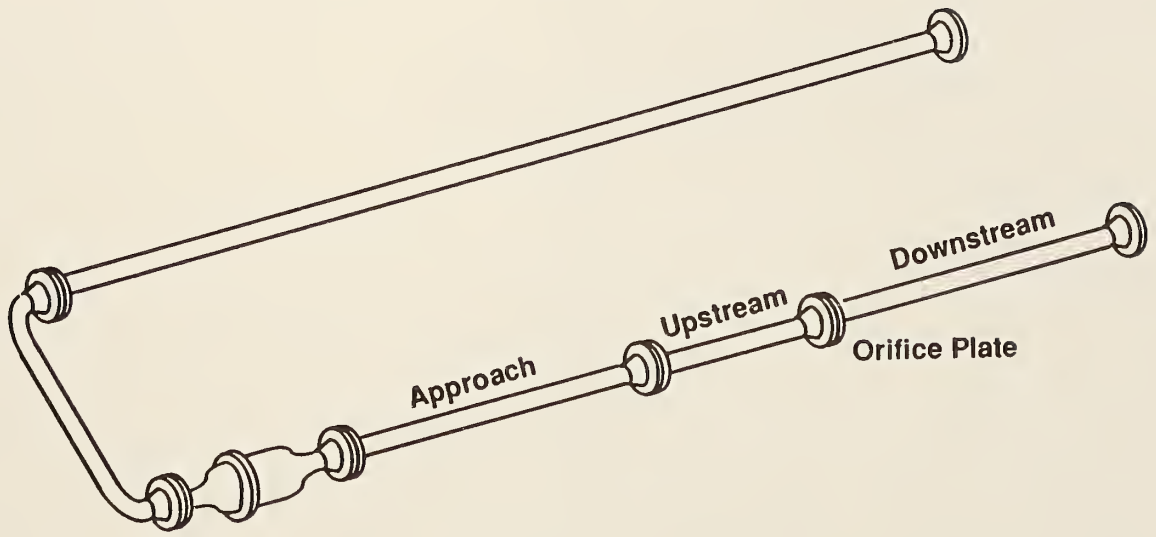


Figure 3. Orifice meter schematic.

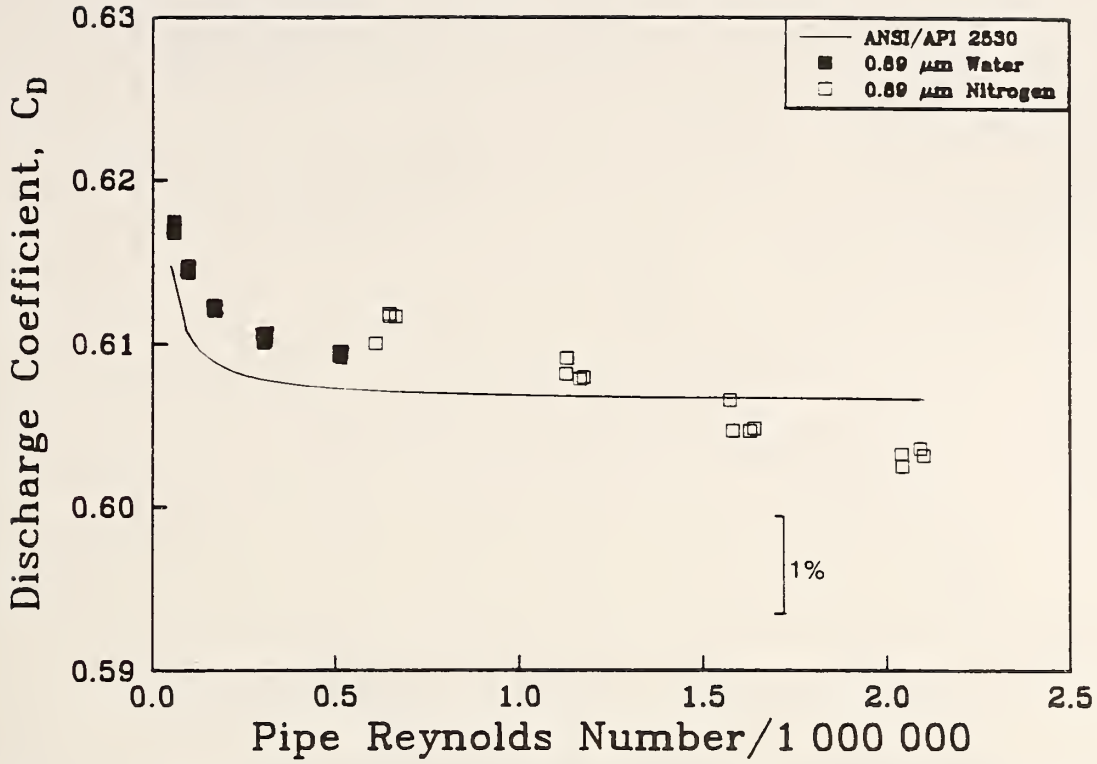


Figure 4. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.65 in a 3-in meter tube with an upstream pipe roughness of 0.89 μm (35 μin).

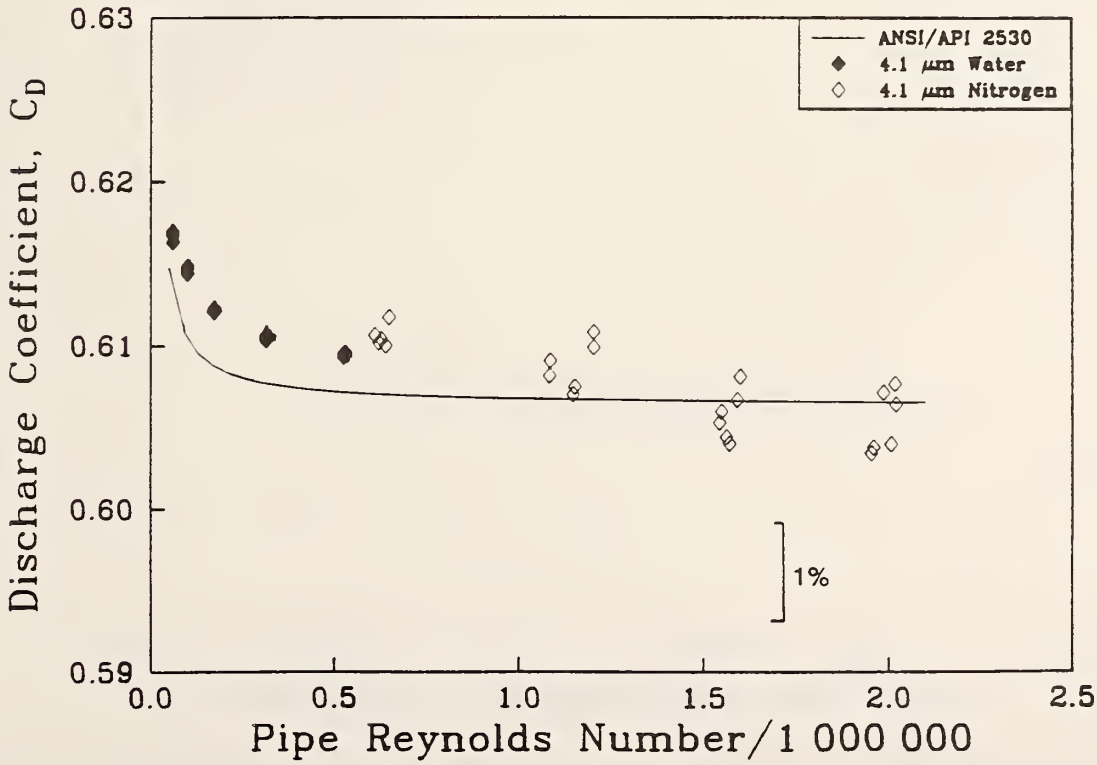


Figure 5. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.65 in a 3-in meter tube with an upstream pipe roughness of 4.1 μm (160 μin).

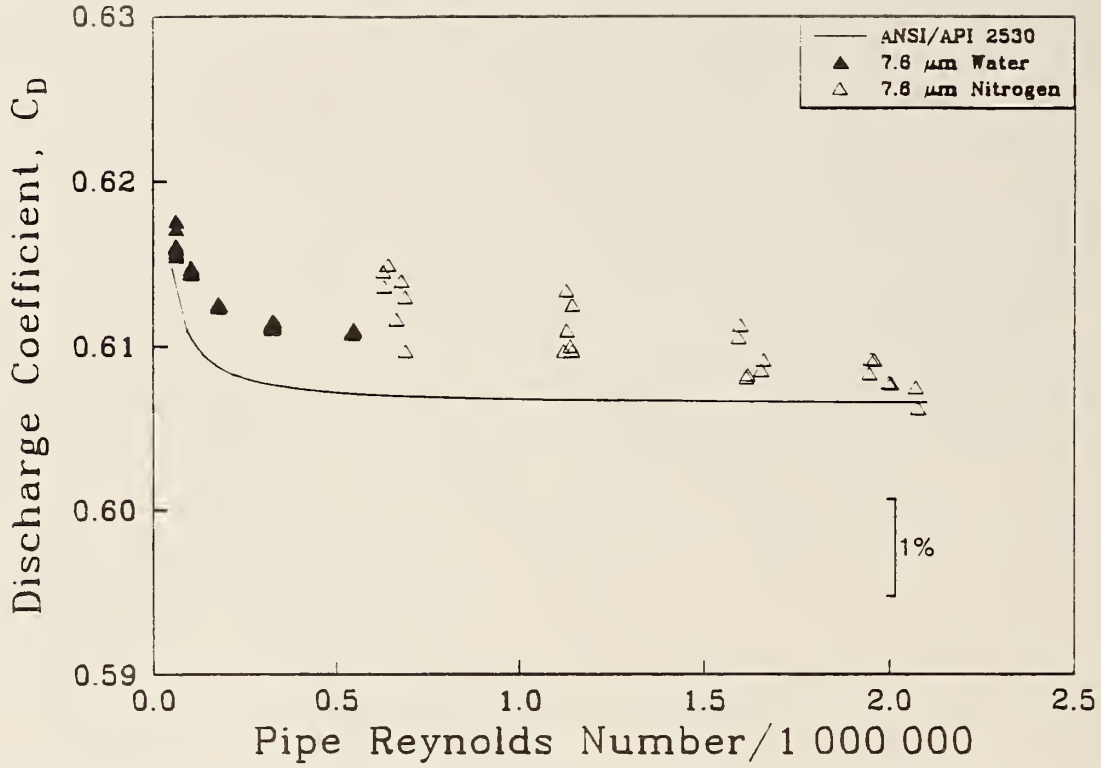


Figure 6. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.65 in a 3-in meter tube with an upstream pipe roughness of 7.6 μm (300 μin).

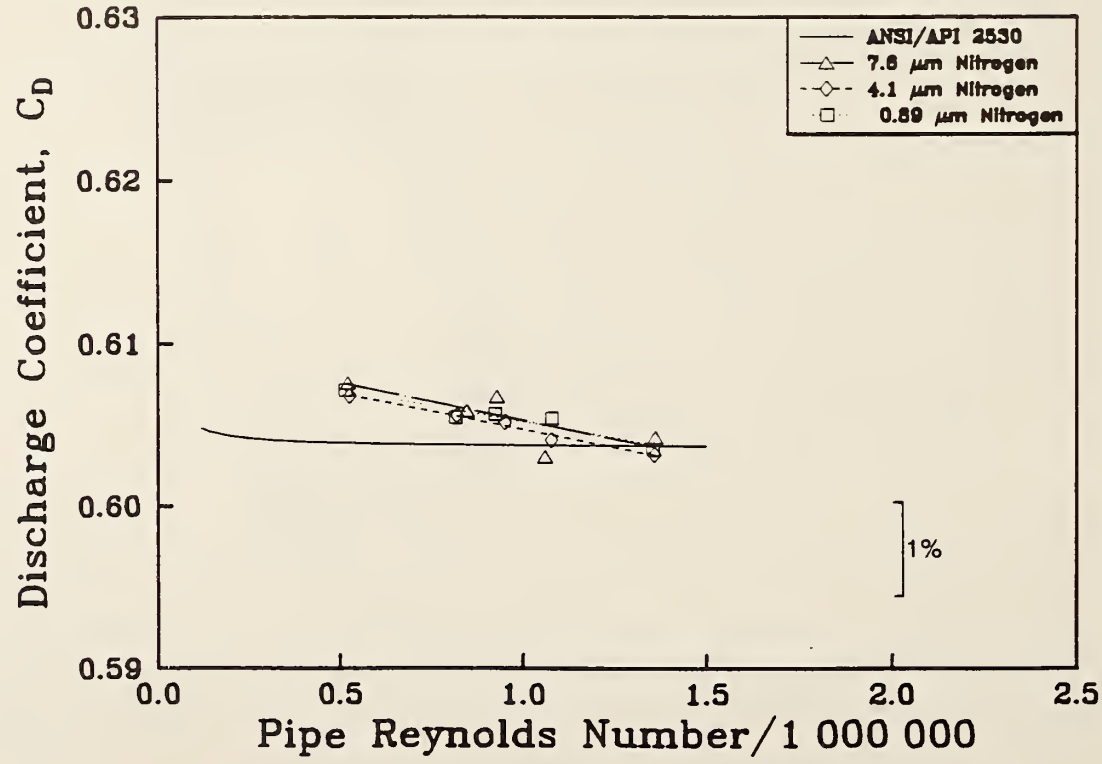


Figure 7. Discharge coefficient vs. Reynolds no. in nitrogen gas for a beta ratio of 0.49 in a 3-in meter tube with upstream pipe roughnesses of 0.89, 4.1, and 7.6 μm (35, 160, and 300 μin).

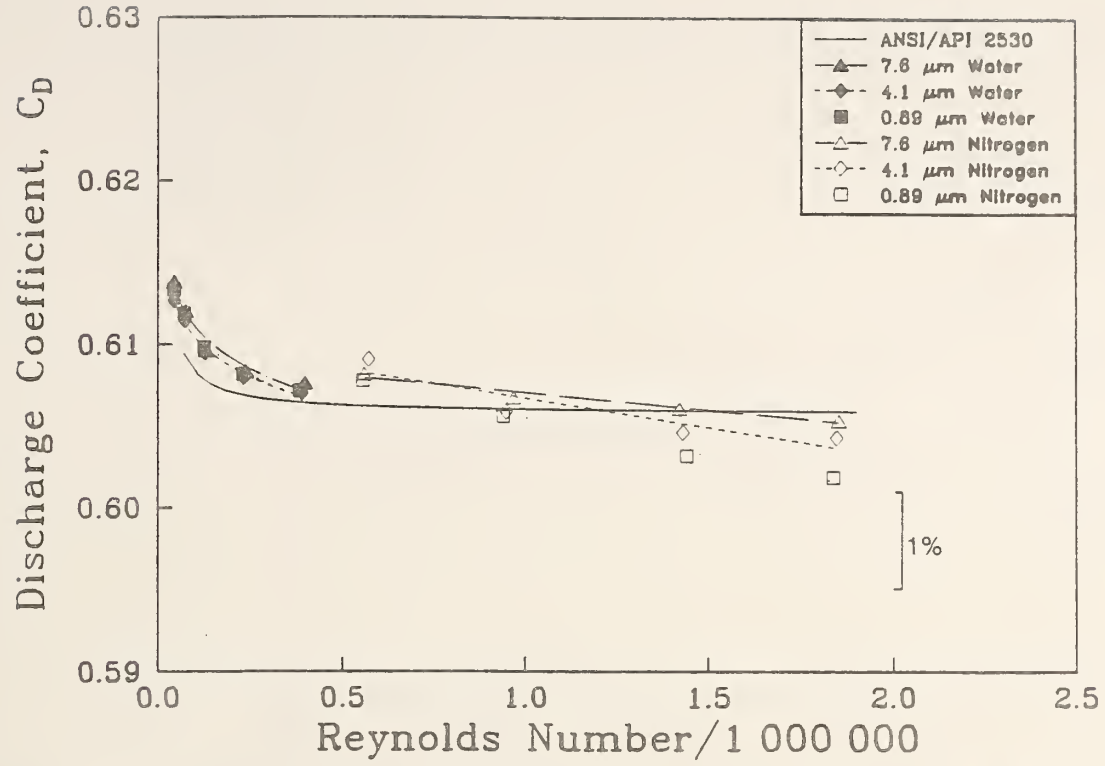


Figure 8. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.57 in a 3-in meter tube with upstream pipe roughnesses of 0.89, 4.1, and 7.6 μm (35, 160, and 300 μin).

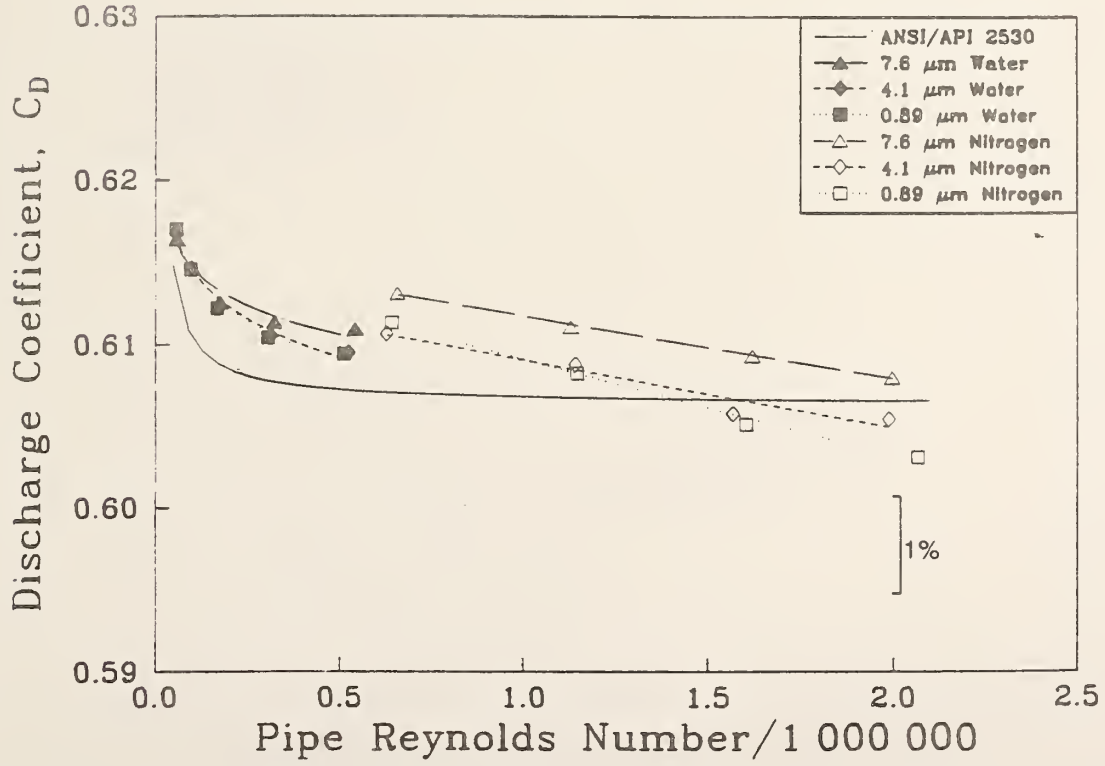


Figure 9. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.65 in a 3-in meter tube with upstream pipe roughnesses of 0.89, 4.1, and 7.6 mm (35, 160, and 300 μin).

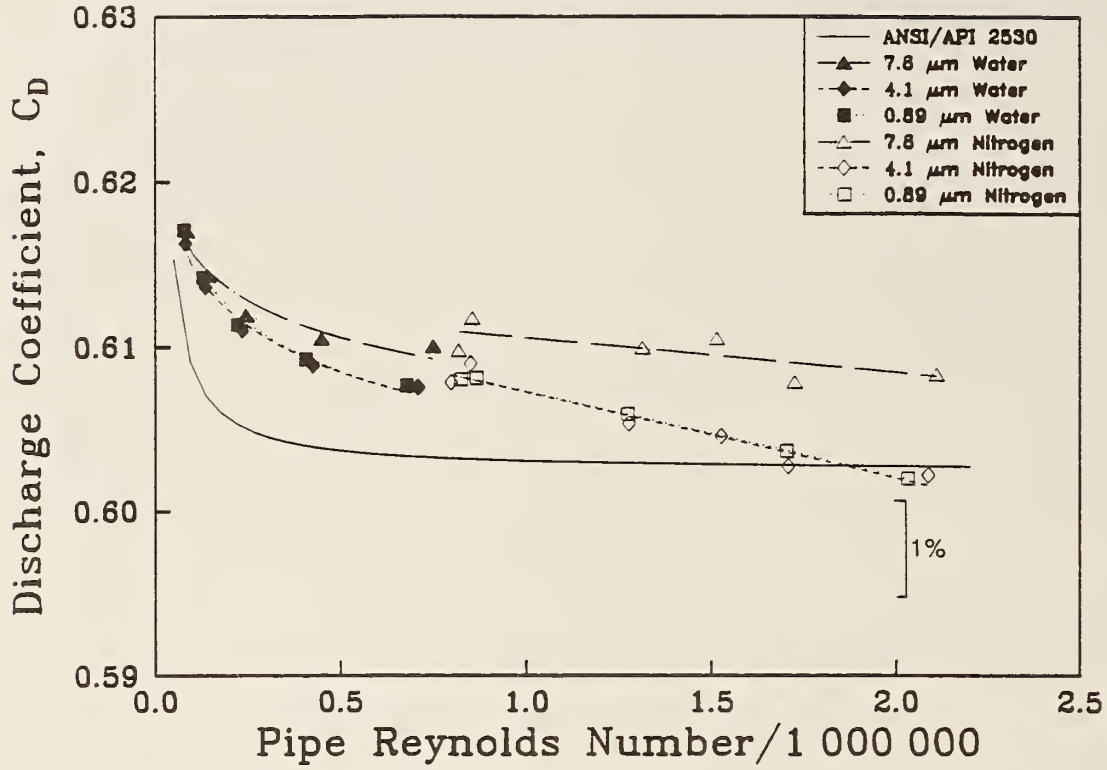


Figure 10. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.73 in a 3-in meter tube with upstream pipe roughnesses of 0.89, 4.1, and 7.6 μm (35, 160, and 300 μin).

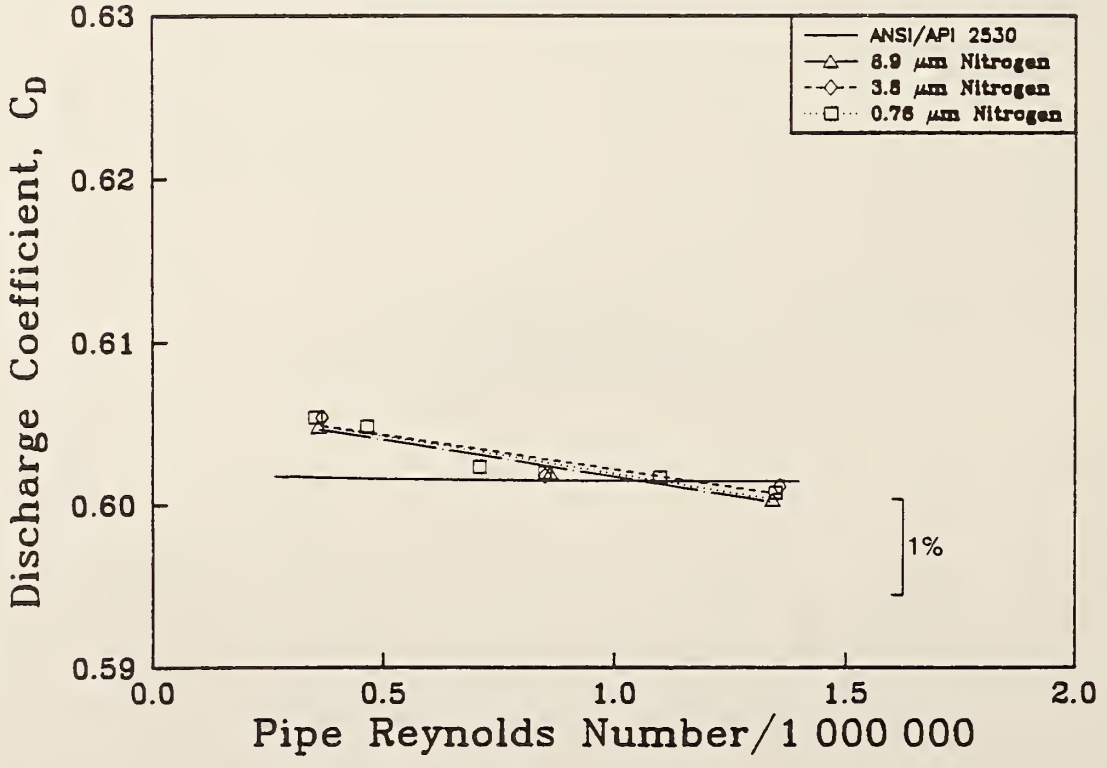


Figure 11. Discharge coefficient vs. Reynolds no. in nitrogen gas for a beta ratio of 0.43 in a 4-in meter tube with upstream pipe roughnesses of 0.76, 3.8, and 6.9 μm (30, 150, and 270 μin).

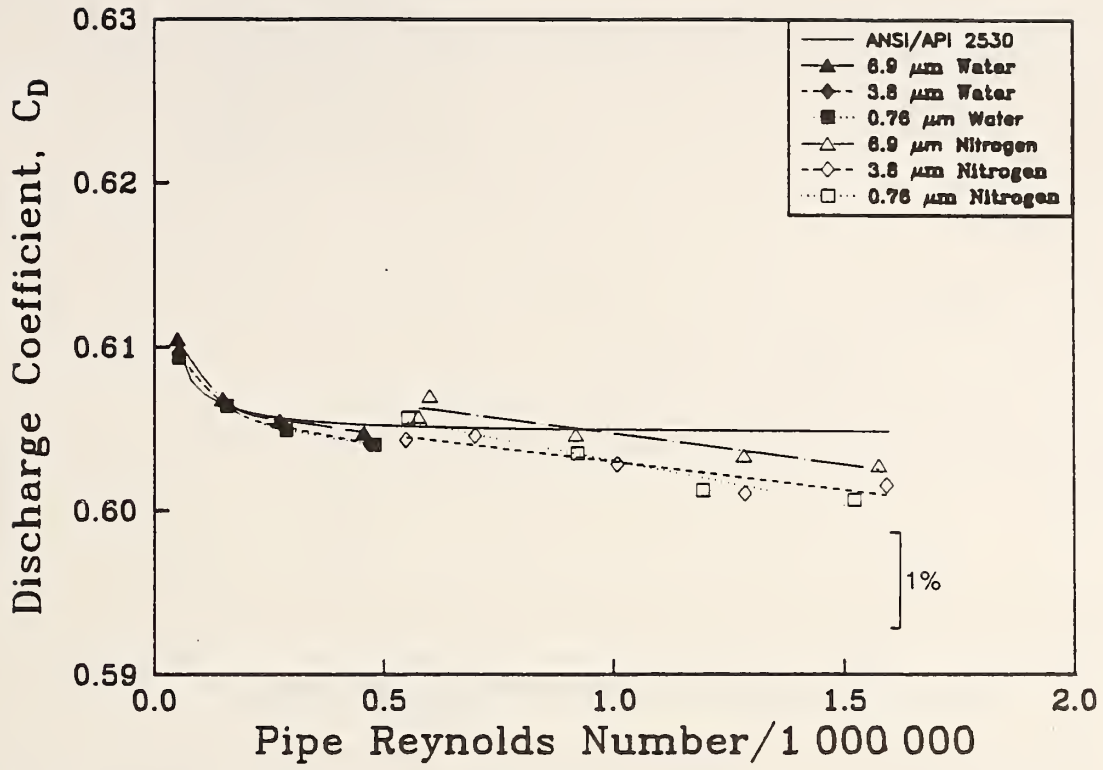


Figure 12. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.55 in a 4-in meter tube with upstream pipe roughnesses of 0.76, 3.8, and 6.9 μm (30, 150, and 270 μin).

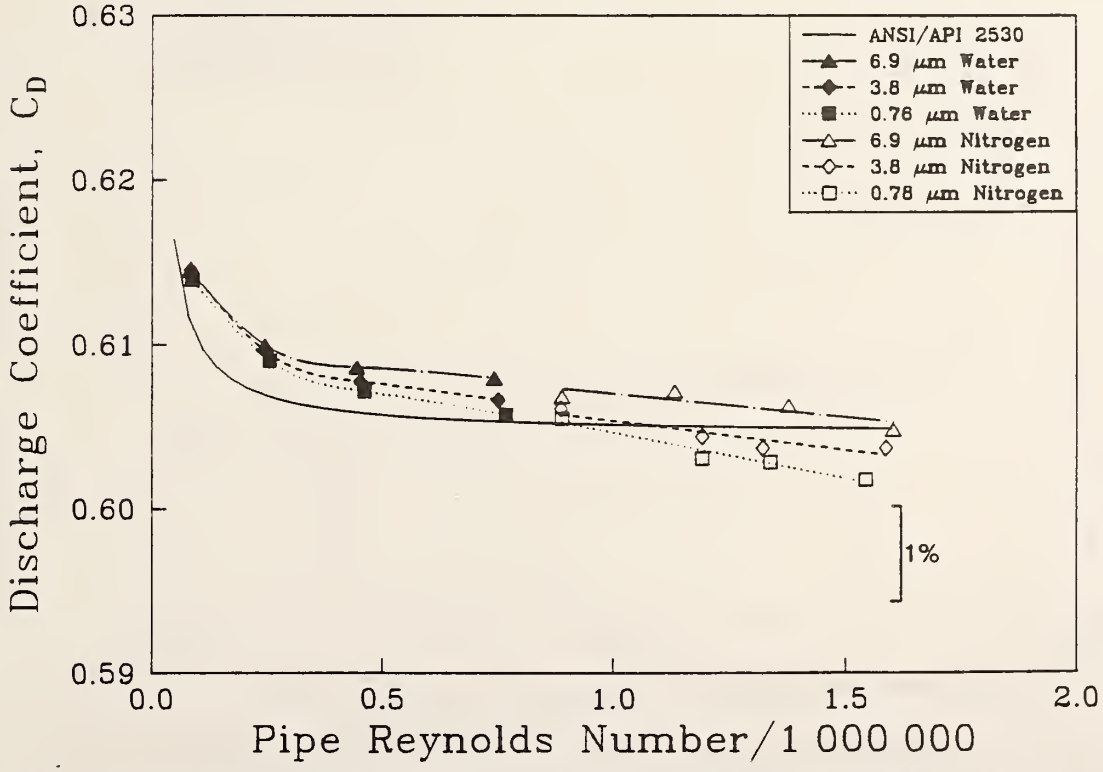


Figure 13. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.67 in a 4-in meter tube with upstream roughnesses of 0.76, 3.8, and 6.9 μm (30, 150, and 270 μin).

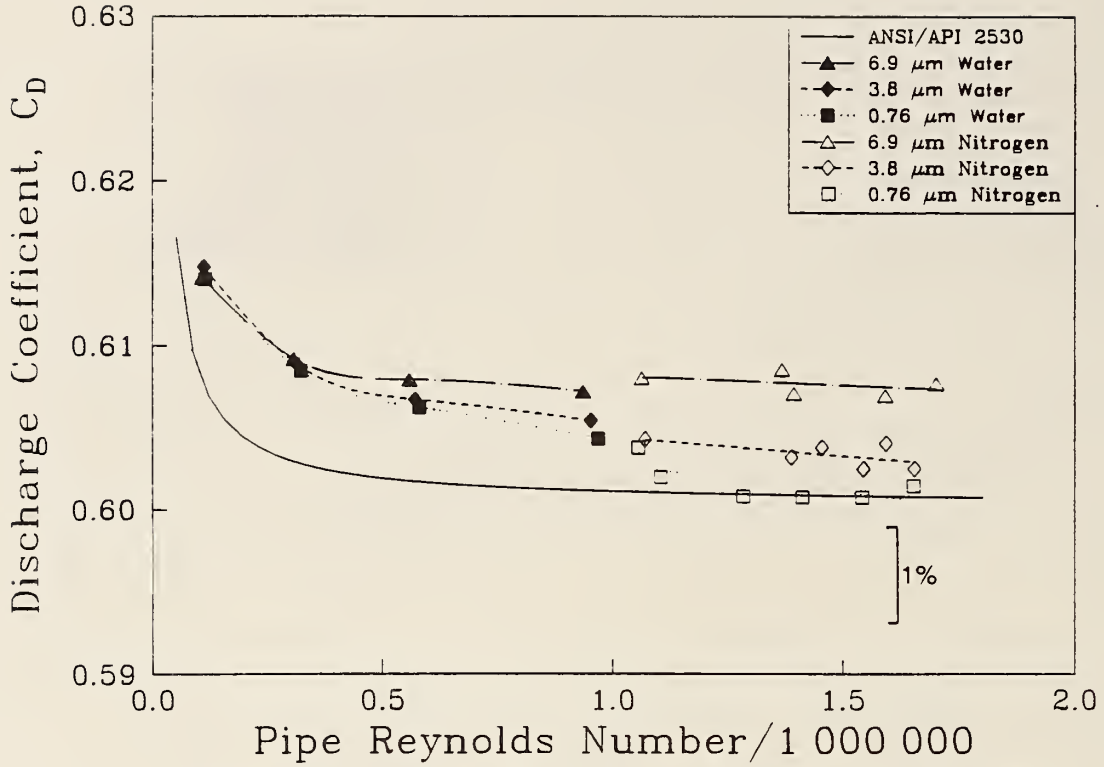


Figure 14. Discharge coefficient vs. Reynolds no. in water and nitrogen gas for a beta ratio of 0.73 in a 4-in meter tube with upstream roughnesses of 0.76, 3.8, and 6.9 μm (30, 150, and 270 μin).

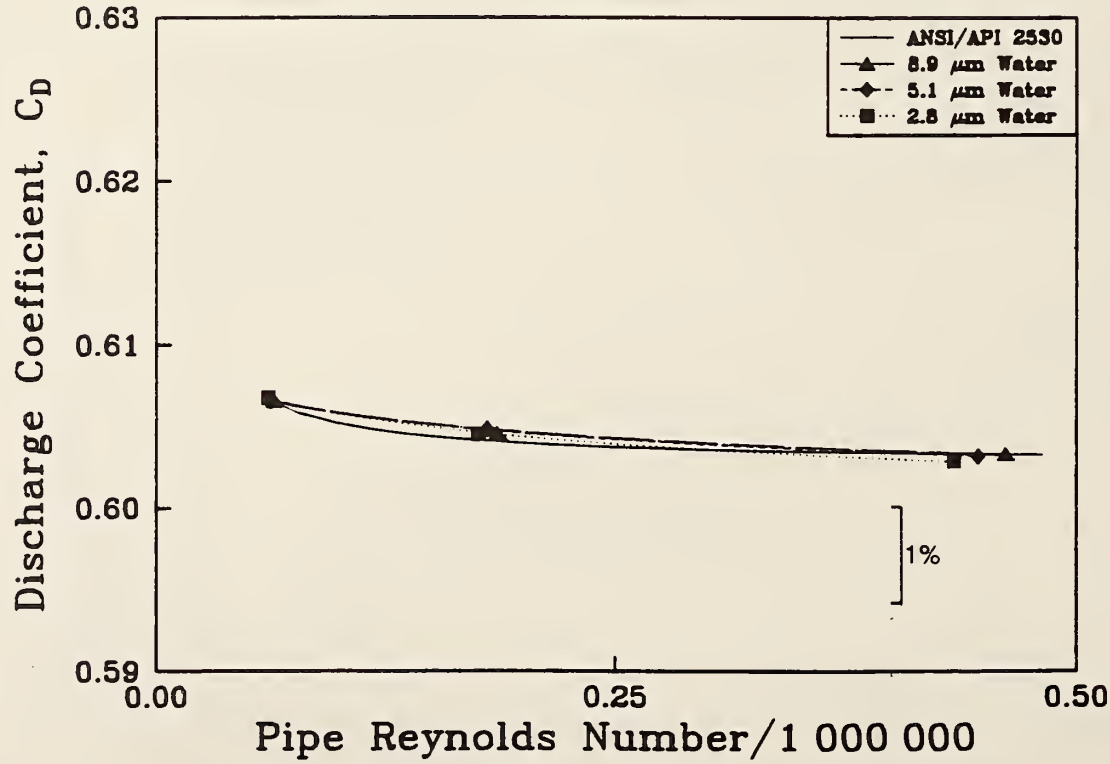


Figure 15. Discharge coefficient vs. Reynolds no. in water for a beta ratio of 0.49 in a 6-in meter tube with upstream pipe roughnesses of 2.8, 5.1, and 8.9 μm (110, 200, and 350 μin).

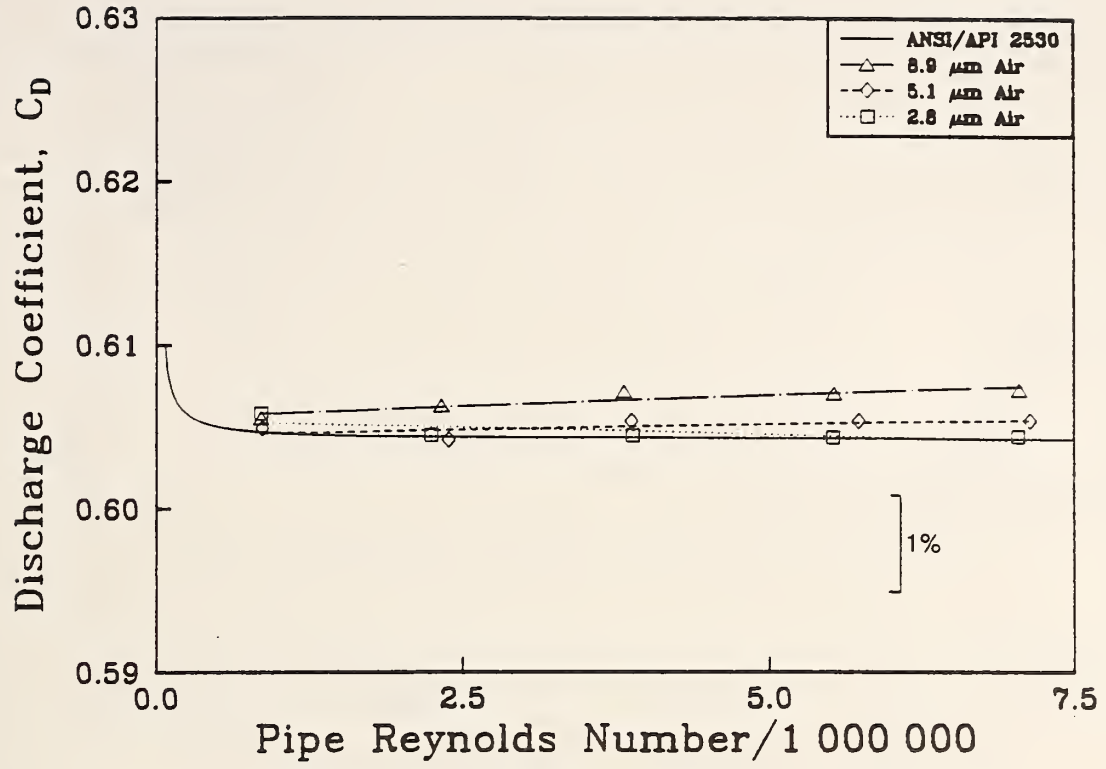


Figure 16. Discharge coefficient vs. Reynolds no. in air for a beta ratio of 0.57 in a 6-in meter tube with upstream pipe roughnesses of 2.8, 5.1 and 8.9 μm (110, 200, and 350 μin).

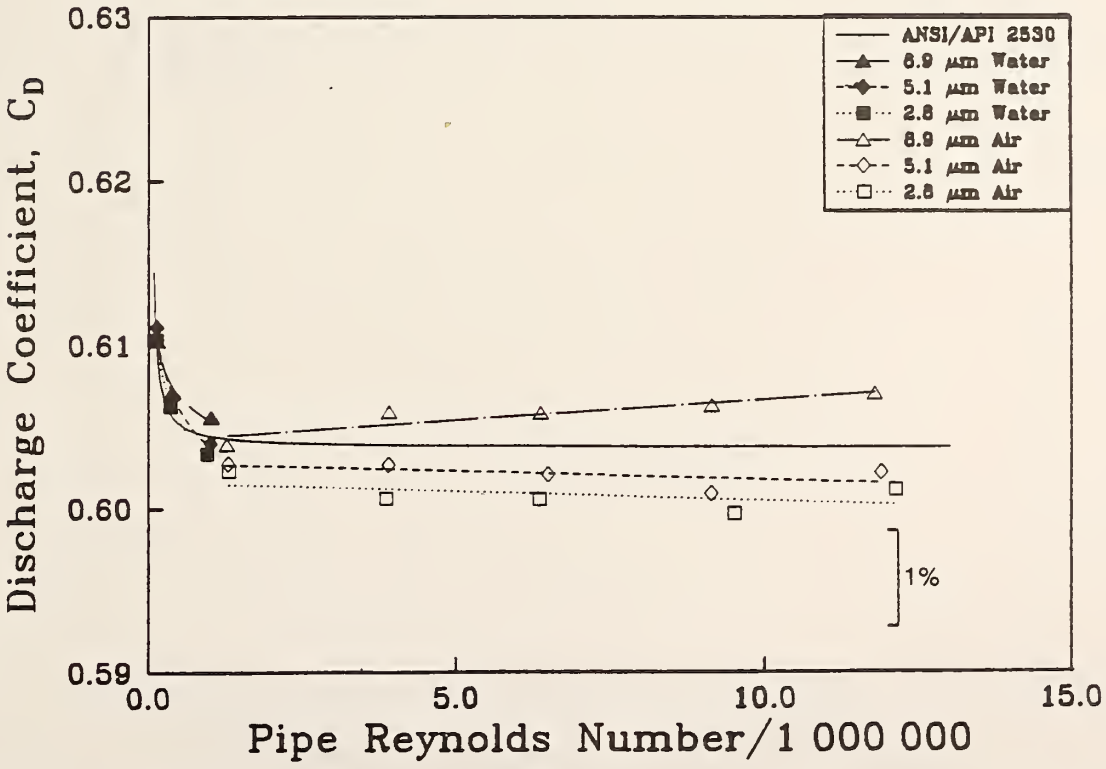


Figure 17. Discharge coefficient vs. Reynolds no. in water and air for a beta ratio of 0.66 in a 6-in meter tube with upstream roughnesses of 2.8, 5.1 and 8.9 μm (110, 200, and 350 μin).

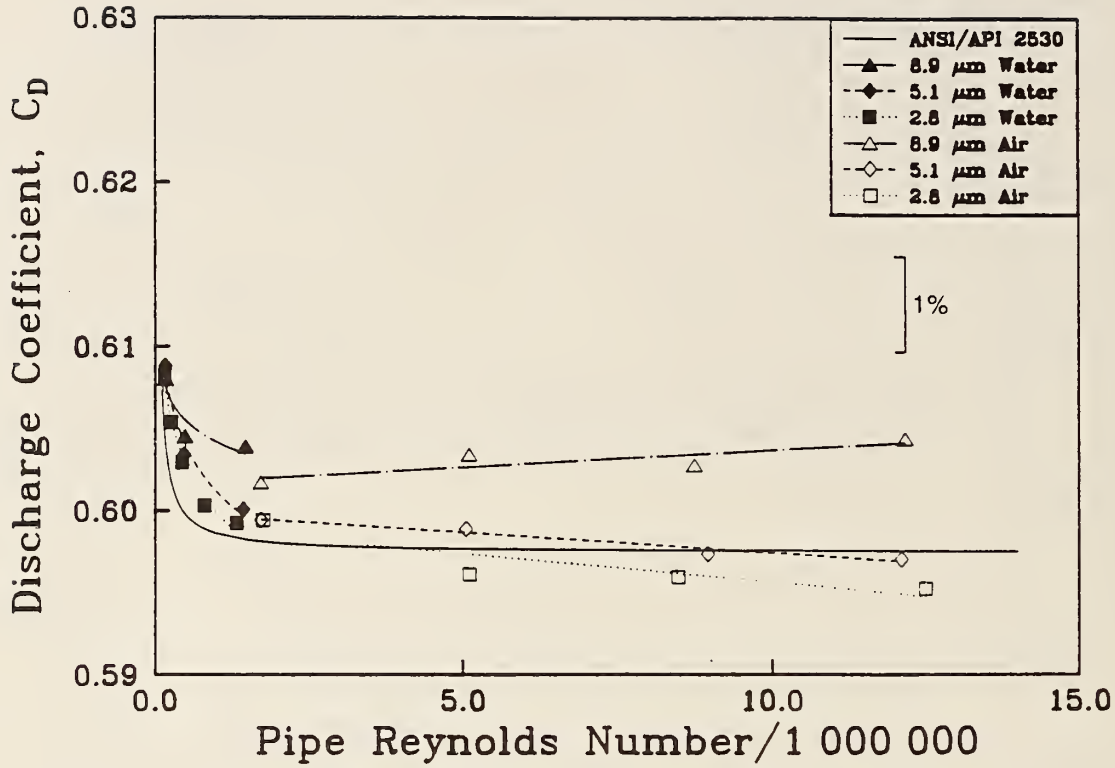


Figure 18. Discharge coefficient vs. Reynolds no. in water and air for a beta ratio of 0.74 in a 6-in meter tube with upstream roughnesses of 2.8, 5.1 and 8.9 μm (110, 200, and 350 μin).

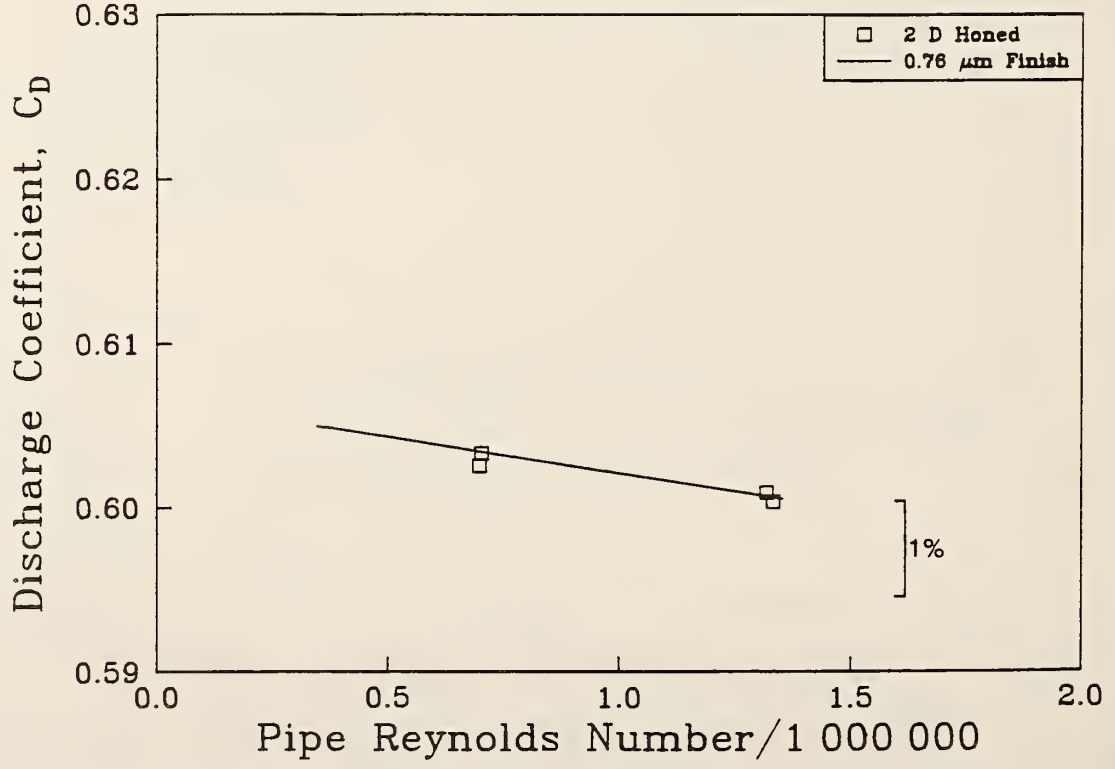


Figure 19. Discharge coefficient vs. Reynolds no. for 0.43 beta ratio in a 4-in meter tube with an upstream rough pipe honed smooth for two pipe diameters from the orifice plate.

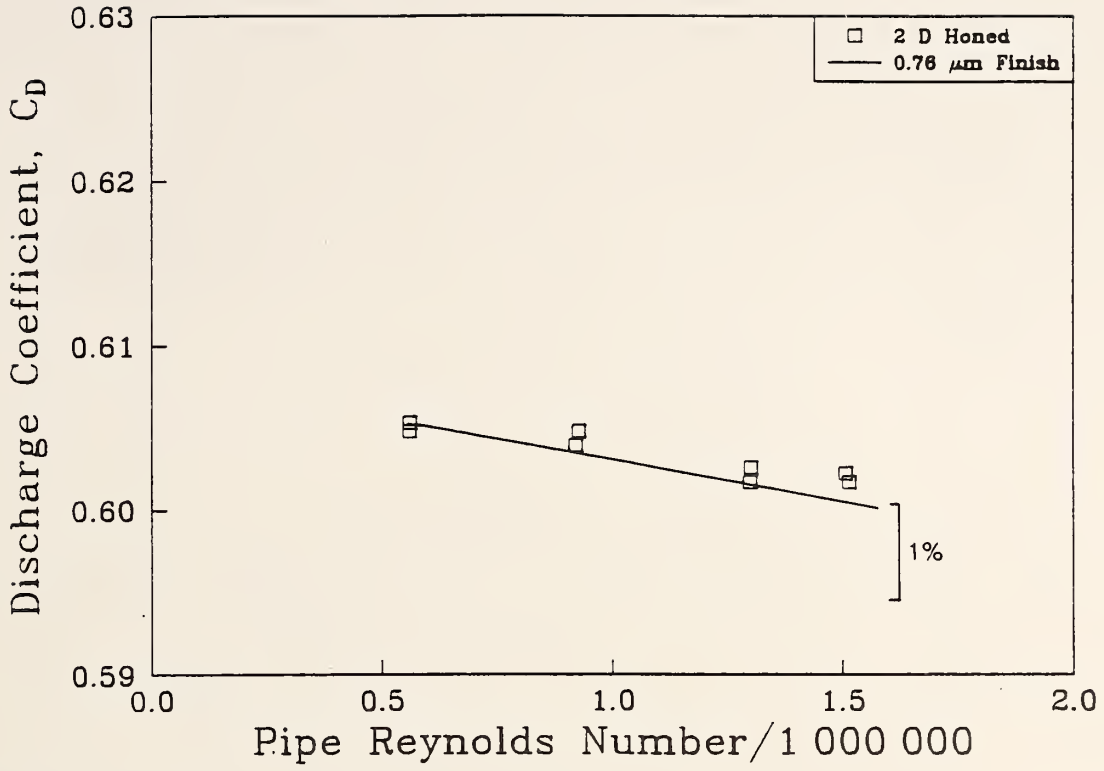


Figure 20. Discharge coefficient vs. Reynolds no. for 0.55 beta ratio in a 4-in meter tube with an upstream rough pipe honed smooth for two pipe diameters from the orifice plate.

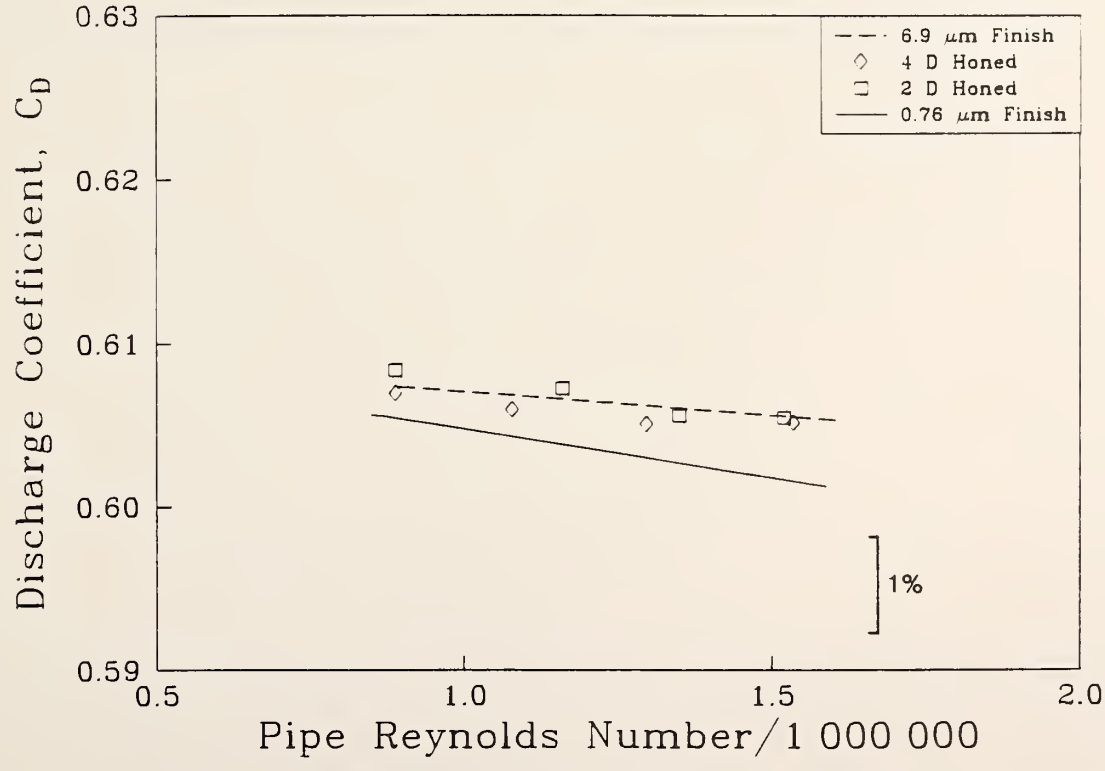


Figure 21. Discharge coefficient vs. Reynolds no. for 0.67 beta ratio in a 4-in meter tube with an upstream rough pipe honed smooth for two and four pipe diameters from the orifice plate.

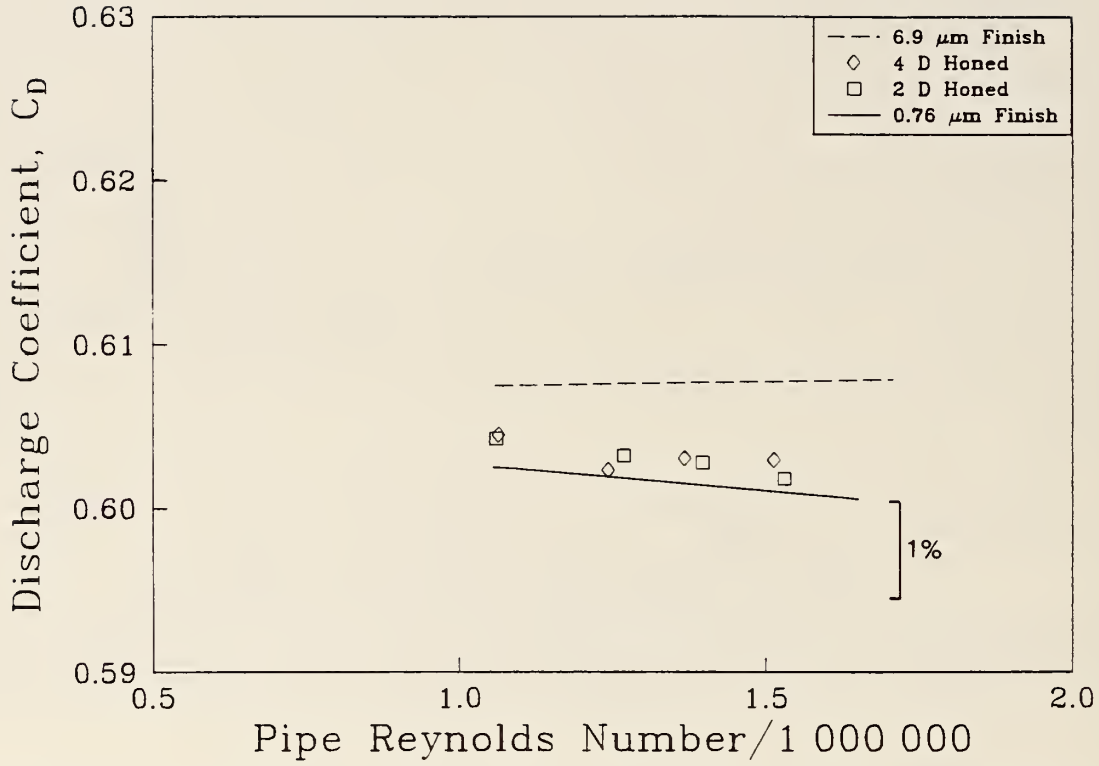


Figure 22. Discharge coefficient vs. Reynolds no. for 0.73 beta ratio in a 4-in meter tube with an upstream rough pipe honed smooth for two and four pipe diameters from the orifice plate.

APPENDIX

Measured and Calculated Quantities in SI Units for the Upstream Pipe Roughness Study

CONVERSION FACTORS

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

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Table 1. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.49 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 3.8087 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
33042787- 1	4.0053	288.49	47.13	22.286	1.0287	923100	0.6046	0.6053
33042787- 2	4.0034	288.78	47.05	22.286	1.0315	925000	0.6067	0.6074
33042787- 3	4.0991	289.51	48.05	6.174	0.5483	490200	0.6070	0.6072
33042787- 4	4.1137	289.54	48.22	6.260	0.5522	493700	0.6062	0.6064
33042787- 5	3.8909	289.77	45.56	49.487	1.5084	1351300	0.6041	0.6057
33042787- 6	3.9102	289.27	45.87	49.237	1.5086	1352700	0.6037	0.6053
33042787- 7	3.9845	289.53	46.70	31.614	1.2217	1093900	0.6053	0.6063
33042787- 8	3.9923	290.07	46.69	31.807	1.2240	1094400	0.6046	0.6056
33102287- 1	3.9630	286.28	47.03	29.795	1.1940	1077600	0.6073	0.6083
33102287- 2	3.9568	288.09	46.63	29.755	1.1839	1063900	0.6051	0.6061
33102287- 3	3.9558	287.82	46.66	29.628	1.1806	1061600	0.6045	0.6054
33102287- 4	3.8929	288.94	45.72	49.503	1.5088	1354100	0.6031	0.6047
33102287- 5	3.8795	288.53	45.64	49.486	1.5064	1353400	0.6028	0.6044
33102287- 2	4.0557	286.49	48.09	16.900	0.9059	816200	0.6054	0.6060
33102287- 3	4.1244	288.28	48.57	7.304	0.6012	538900	0.6086	0.6088
33102287- 4	4.1351	287.66	48.82	7.032	0.5894	529100	0.6066	0.6069

Table 2. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.49 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 3.8087 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
33031087- 1	3.9191	287.46	46.29	48.302	1.5021	1352900	0.6042	0.6057
33031087- 2	3.9202	287.48	46.30	48.155	1.5000	1350800	0.6042	0.6057
33031087- 3	4.0575	288.33	47.78	23.693	1.0705	960500	0.6060	0.6067
33031087- 4	4.0524	287.87	47.80	23.754	1.0718	962800	0.6058	0.6066
33031087- 5	4.1180	288.83	48.40	6.714	0.5742	514200	0.6075	0.6077
33031087- 6	4.1309	288.92	48.53	6.003	0.5431	486200	0.6069	0.6071
33041687- 1	3.8723	287.99	45.65	49.616	1.5101	1359000	0.6035	0.6051
33041687- 2	3.8724	288.35	45.59	49.664	1.5102	1358000	0.6036	0.6052
33041687- 3	4.1060	289.30	48.17	6.918	0.5807	519500	0.6065	0.6068
33041687- 4	4.1013	289.33	48.11	7.147	0.5897	527600	0.6064	0.6066
33041687- 5	3.9976	287.36	47.24	29.985	1.1949	1075400	0.6045	0.6054
33041687- 7	4.0088	288.13	47.24	29.749	1.1919	1070500	0.6054	0.6063
33041687- 8	4.0818	288.61	48.01	16.632	0.8988	805700	0.6060	0.6065
33041687- 9	4.0714	288.90	47.83	16.636	0.8972	803700	0.6059	0.6065
33110987- 1	3.9464	287.62	46.59	31.135	1.2089	1088100	0.6043	0.6053
33110987- 2	3.9346	287.68	46.44	30.853	1.1969	1077300	0.6020	0.6030
33110987- 3	4.0388	288.12	47.59	18.105	0.9320	836900	0.6048	0.6054
33110987- 4	4.0405	288.21	47.60	18.159	0.9342	838600	0.6054	0.6059
33110987- 5	3.8918	287.59	45.95	48.152	1.4895	1341500	0.6023	0.6038
33110987- 6	3.8769	287.75	45.74	48.788	1.4940	1345300	0.6015	0.6030
33110987- 7	4.1191	289.14	48.35	8.303	0.6377	570600	0.6066	0.6069
33110987- 8	4.1580	289.17	48.80	8.574	0.6505	581800	0.6062	0.6064

Table 3. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.49 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 3.8087 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
33031287- 1	3.9127	287.62	46.19	49.727	1.5287	1377000	0.6066	0.6082
33031287- 2	3.9135	287.72	46.18	49.447	1.5206	1369300	0.6051	0.6067
33031287- 3	4.0613	289.13	47.67	23.246	1.0615	950900	0.6072	0.6080
33031287- 4	4.0456	288.89	47.53	23.257	1.0600	950400	0.6072	0.6079
33031287- 5	4.1565	288.24	48.96	6.131	0.5520	495000	0.6077	0.6079
33031287- 6	4.1684	288.29	49.09	6.434	0.5661	507500	0.6074	0.6076
33032687- 1	4.1599	288.36	48.98	6.910	0.5854	524800	0.6067	0.6069
33032687- 2	4.1513	288.21	48.91	6.710	0.5761	516600	0.6063	0.6065
33032687- 3	3.9146	287.96	46.15	48.328	1.4991	1349100	0.6037	0.6052
33032687- 4	3.9149	288.69	46.03	48.140	1.4925	1340900	0.6030	0.6046
33032687- 5	4.0616	288.94	47.71	21.532	1.0212	915300	0.6068	0.6075
33032687- 6	4.0403	289.43	47.37	21.501	1.0150	908900	0.6057	0.6064
33110487- 1	4.0023	288.62	47.07	7.997	0.6164	553300	0.6057	0.6059
33110487- 2	4.0034	288.56	47.09	8.320	0.6311	566500	0.6077	0.6080
33110487- 3	3.8048	287.04	45.01	45.647	1.4388	1299400	0.6038	0.6053
33110487- 4	3.7956	288.50	44.65	48.477	1.4733	1326000	0.6022	0.6038
33110487- 5	3.8356	288.89	45.06	30.776	1.1805	1061000	0.6035	0.6045
33110487- 6	3.8380	288.97	45.07	30.866	1.1807	1060900	0.6025	0.6035
33110487- 7	3.9372	289.32	46.18	19.067	0.9441	846600	0.6060	0.6066
33110487- 8	3.9495	289.43	46.30	19.265	0.9497	851300	0.6057	0.6063

Table 4. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.57 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 4.4432 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
06/25/87- 1	300.61	2.574	2.282	43972	0.61355
06/25/87- 2	300.64	2.569	2.281	43966	0.61371
06/25/87- 3	300.69	2.563	2.278	43961	0.61373
06/25/87- 4	300.75	6.904	3.724	71974	0.61140
06/25/87- 5	300.78	7.143	3.790	73292	0.61165
06/25/87- 6	300.78	6.991	3.755	72605	0.61251
06/25/87- 7	300.81	6.955	3.744	72431	0.61220
06/25/87- 8	300.83	6.941	3.740	72396	0.61226
06/25/87- 9	300.84	6.910	3.733	72265	0.61240
06/25/87-10	300.89	7.122	3.784	73352	0.61167
06/25/87-11	300.95	7.120	3.784	73458	0.61172
06/25/87-12	300.99	7.086	3.775	73340	0.61167
06/25/87-13	301.09	20.788	6.446	125501	0.60982
06/25/87-14	301.11	20.847	6.456	125739	0.60985
06/25/87-15	301.15	20.722	6.437	125495	0.60998
06/25/87-16	301.23	69.119	11.725	228953	0.60830
06/25/87-17	301.25	69.101	11.721	228970	0.60817
06/25/87-18	301.27	68.922	11.705	228766	0.60816
06/25/87-19	301.32	192.516	19.534	382177	0.60727
06/25/87-20	301.33	192.495	19.531	382195	0.60720
06/25/87-21	301.35	192.419	19.526	382342	0.60717
06/26/87-22	300.76	2.582	2.283	44129	0.61280
06/26/87-23	300.78	2.567	2.277	44028	0.61296
06/26/87-24	300.80	2.586	2.286	44228	0.61323
06/26/87-25	300.85	2.528	2.262	43804	0.61359
06/26/87-26	300.87	2.531	2.262	43827	0.61332
06/26/87-27	300.89	2.541	2.267	43947	0.61350
06/26/87-28	301.04	6.981	3.752	72967	0.61245
06/26/87-29	301.05	6.924	3.734	72628	0.61201
06/26/87-30	301.07	6.872	3.719	72379	0.61195
06/26/87-31	301.14	6.883	3.719	72489	0.61146
06/26/87-32	301.19	6.863	3.714	72475	0.61159
06/26/87-33	301.23	6.865	3.715	72547	0.61163
06/26/87-34	301.31	20.636	6.423	125636	0.60988
06/26/87-35	301.34	20.672	6.428	125819	0.60984
06/26/87-36	301.37	20.612	6.417	125709	0.60968
06/26/87-37	301.46	68.955	11.708	229798	0.60819
06/26/87-38	301.52	69.571	11.762	231139	0.60825
06/26/87-39	301.52	68.801	11.695	229823	0.60816
06/26/87-40	301.60	192.625	19.538	384610	0.60724
06/26/87-41	301.60	192.835	19.543	384708	0.60706
06/26/87-42	301.61	192.796	19.547	384865	0.60724

Table 5. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.57 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 4.4432 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
34042987- 1	3.7854	287.31	44.74	49.069	2.0839	1880300	0.6056	0.6071
34042987- 2	3.7867	288.01	44.63	49.117	2.0833	1876600	0.6058	0.6073
34042987- 3	4.1497	286.64	49.18	3.498	0.5865	527700	0.6106	0.6107
34042987- 4	4.1264	286.46	48.94	4.374	0.6552	590000	0.6115	0.6116
34042987- 5	4.0878	286.18	48.54	11.155	1.0401	937600	0.6099	0.6102
34042987- 6	4.0922	285.92	48.64	11.133	1.0401	938200	0.6099	0.6102
34042987- 7	3.9276	284.69	46.89	27.417	1.6005	1450800	0.6085	0.6094
34042987- 8	3.9266	284.61	46.90	27.200	1.5925	1443900	0.6078	0.6087
34042987- 9	3.9320	288.79	46.21	27.468	1.5876	1424800	0.6074	0.6082
34102687- 1	4.0005	288.26	47.12	11.319	1.0261	921200	0.6062	0.6065
34102687- 2	3.9669	286.89	46.96	11.212	1.0190	918200	0.6059	0.6062
34102687- 3	3.7048	288.82	43.53	50.671	2.0776	1869200	0.6022	0.6039
34102687- 4	3.7143	290.95	43.29	50.994	2.0807	1862200	0.6028	0.6044
34102687- 5	3.8582	289.23	45.26	29.403	1.6157	1449700	0.6036	0.6045
34102687- 6	3.8440	289.53	45.05	29.541	1.6157	1448800	0.6036	0.6045
34102687- 7	4.0786	290.04	47.71	3.629	0.5866	523900	0.6086	0.6087
34102687- 8	4.0744	288.59	47.93	3.987	0.6151	551300	0.6074	0.6075
34102787- 1	3.9895	285.87	47.42	12.180	1.0665	963100	0.6054	0.6058
34102787- 2	3.9876	288.13	46.99	12.254	1.0666	958000	0.6064	0.6068
34102787- 3	3.7754	287.87	44.52	47.311	2.0283	1827600	0.6018	0.6033
34102787- 4	3.7794	288.50	44.46	47.400	2.0302	1826400	0.6022	0.6036
34102787- 5	3.8867	287.39	45.92	28.758	1.6078	1448500	0.6031	0.6040
34102787- 6	3.8862	284.77	46.38	28.651	1.6129	1462300	0.6031	0.6040
34102787- 7	4.1293	284.52	49.35	3.497	0.5854	529500	0.6084	0.6085
34102787- 8	4.1274	287.04	48.84	3.904	0.6149	552800	0.6080	0.6081
34111287- 1	3.8924	288.27	45.84	12.166	1.0469	941100	0.6048	0.6051
34111287- 2	3.8876	288.23	45.78	12.136	1.0449	939400	0.6047	0.6051
34111287- 3	3.8141	287.79	44.99	26.930	1.5394	1386600	0.6028	0.6037
34111287- 4	3.8136	287.64	45.01	29.256	1.6040	1445400	0.6024	0.6033
34111287- 5	4.0385	288.33	47.55	4.438	0.6465	580000	0.6075	0.6076
34111287- 6	4.0249	288.45	47.37	4.568	0.6536	586300	0.6065	0.6067
34111287- 7	3.7281	286.28	44.23	47.514	2.0249	1832600	0.6015	0.6030
34111287- 8	3.6852	287.51	43.51	47.085	1.9964	1802300	0.6005	0.6020

Table 6. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.57 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 4.4432 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
06/30/87- 2	301.60	2.572	2.277	44896	0.61257
06/30/87- 3	301.62	2.573	2.279	44941	0.61280
06/30/87- 4	301.68	2.553	2.272	44850	0.61316
06/30/87- 5	301.74	7.045	3.767	74483	0.61220
06/30/87- 6	301.76	7.048	3.766	74480	0.61182
06/30/87- 7	301.77	7.036	3.762	74417	0.61167
06/30/87- 8	301.82	7.044	3.759	74456	0.61085
06/30/87- 9	301.87	7.055	3.762	74604	0.61098
06/30/87-10	301.92	7.034	3.756	74566	0.61092
06/30/87-11	302.05	20.900	6.459	128561	0.60940
06/30/87-12	302.08	20.917	6.462	128712	0.60949
06/30/87-13	302.12	20.870	6.454	128658	0.60941
06/30/87-14	302.15	68.958	11.701	233386	0.60778
06/30/87-15	302.19	68.978	11.702	233607	0.60776
06/30/87-16	302.20	68.950	11.705	233711	0.60803
06/30/87-17	302.24	192.783	19.543	390625	0.60713
06/30/87-18	302.24	193.945	19.591	391587	0.60680
06/30/87-19	302.24	192.072	19.505	389869	0.60708
06/30/87-20	302.27	192.787	19.538	390780	0.60699
06/30/87-21	302.26	192.790	19.536	390665	0.60693
06/30/87-22	302.27	192.735	19.530	390613	0.60681
07/01/87-23	301.58	2.574	2.277	44877	0.61238
07/01/87-24	301.60	2.577	2.280	44940	0.61256
07/01/87-25	301.63	2.566	2.274	44851	0.61227
07/01/87-26	301.70	7.154	3.797	75001	0.61228
07/01/87-27	301.71	7.067	3.769	74476	0.61160
07/01/87-28	301.73	7.092	3.776	74636	0.61155
07/01/87-29	301.82	7.059	3.763	74536	0.61089
07/01/87-30	301.87	7.050	3.760	74568	0.61088
07/01/87-31	301.92	7.041	3.759	74618	0.61106
07/01/87-32	302.04	21.123	6.493	129205	0.60935
07/01/87-33	302.07	21.185	6.504	129507	0.60950
07/01/87-34	302.12	21.190	6.503	129631	0.60937
07/01/87-35	302.21	68.817	11.692	233510	0.60796
07/01/87-36	302.22	68.974	11.707	233900	0.60803
07/01/87-37	302.25	68.806	11.690	233713	0.60790
07/01/87-38	302.29	192.728	19.530	390772	0.60681
07/01/87-39	302.31	193.329	19.566	391663	0.60700
07/01/87-40	302.30	193.062	19.556	391387	0.60712

Table 7. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.57 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 4.4432 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
34031787- 1	4.1429	289.01	48.66	4.281	0.6456	577700	0.6106	0.6107
34031787- 2	4.1604	288.92	48.88	3.773	0.6067	542900	0.6098	0.6099
34031787- 3	3.9486	289.21	46.33	25.931	1.5427	1383000	0.6066	0.6074
34031787- 4	3.9492	289.14	46.35	25.849	1.5421	1382700	0.6073	0.6081
34031787- 5	3.8051	287.57	44.93	48.821	2.0906	1884900	0.6078	0.6093
34031787- 6	3.8060	288.28	44.81	48.562	2.0770	1869400	0.6062	0.6077
34102987- 1	3.9357	287.27	46.53	11.730	1.0397	936700	0.6072	0.6075
34102987- 2	3.9266	287.21	46.43	11.600	1.0321	930100	0.6067	0.6071
34102987- 3	4.0635	286.86	48.12	4.111	0.6268	564400	0.6083	0.6084
34102987- 4	4.0767	286.69	48.31	4.521	0.6604	594800	0.6099	0.6101
34102987- 5	3.7448	288.00	44.14	48.607	2.0543	1851700	0.6038	0.6054
34102987- 6	3.7414	287.97	44.10	48.127	2.0402	1839200	0.6029	0.6044
34102987- 7	3.8575	286.49	45.73	28.816	1.6081	1452800	0.6037	0.6046
34102987- 8	3.8551	286.37	45.73	28.916	1.6111	1456000	0.6039	0.6048
34103087- 1	3.9515	288.31	46.53	12.628	1.0748	965700	0.6048	0.6052
34103087- 2	3.9559	288.30	46.58	12.566	1.0722	963300	0.6045	0.6049
34103087- 3	4.1104	288.51	48.37	3.949	0.6155	551700	0.6080	0.6081
34103087- 4	4.0996	288.53	48.24	4.640	0.6661	597100	0.6077	0.6078
34103087- 5	3.7661	286.88	44.58	46.628	2.0176	1823100	0.6026	0.6040
34103087- 6	3.7636	286.61	44.60	45.970	2.0028	1811000	0.6023	0.6038
34103087- 7	3.8663	286.96	45.76	29.169	1.6180	1460000	0.6036	0.6045
34103087- 8	3.8561	286.86	45.65	29.166	1.6122	1455300	0.6022	0.6031

Table 8. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.57 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 4.4432 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
07/13/87- 1	301.48	2.530	2.263	44519	0.61359
07/13/87- 2	301.51	2.523	2.261	44498	0.61376
07/13/87- 3	301.54	2.498	2.250	44313	0.61393
07/13/87- 4	301.62	7.075	3.779	74570	0.61283
07/13/87- 5	301.63	7.076	3.775	74495	0.61205
07/13/87- 6	301.64	7.093	3.780	74608	0.61213
07/13/87- 7	301.77	7.063	3.767	74566	0.61128
07/13/87- 8	301.80	7.070	3.770	74677	0.61152
07/13/87- 9	301.84	7.034	3.759	74535	0.61139
07/13/87-10	301.88	21.023	6.481	128594	0.60963
07/13/87-11	301.90	21.004	6.478	128592	0.60964
07/13/87-12	301.93	20.931	6.466	128438	0.60957
07/13/87-13	301.98	69.050	11.721	233061	0.60837
07/13/87-14	302.00	69.065	11.719	233122	0.60821
07/13/87-15	302.01	68.992	11.715	233088	0.60831
07/13/87-16	302.10	192.657	19.553	389769	0.60758
07/13/87-17	302.12	192.770	19.556	389989	0.60749
07/13/87-18	302.13	192.599	19.551	389979	0.60762
07/15/87-19	303.71	2.535	2.265	46722	0.61361
07/15/87-20	303.73	2.544	2.268	46824	0.61352
07/15/87-21	303.74	2.511	2.255	46557	0.61399
07/15/87-22	303.83	7.059	3.780	78195	0.61383
07/15/87-23	303.83	7.137	3.789	78377	0.61190
07/15/87-24	303.84	7.052	3.767	77937	0.61200
07/15/87-25	303.91	7.034	3.758	77860	0.61129
07/15/87-26	303.93	7.017	3.754	77817	0.61143
07/15/87-27	303.96	7.028	3.757	77918	0.61139
07/15/87-28	304.02	21.069	6.484	134641	0.60942
07/15/87-29	304.04	21.081	6.486	134731	0.60939
07/15/87-30	304.05	20.882	6.456	134149	0.60952
07/15/87-31	304.10	69.077	11.715	243669	0.60810
07/15/87-32	304.12	68.929	11.703	243519	0.60813
07/15/87-33	304.12	68.833	11.698	243408	0.60828
07/15/87-34	304.16	192.596	19.543	406983	0.60752
07/15/87-35	304.16	192.849	19.553	407207	0.60746
07/15/87-36	304.17	192.732	19.550	407224	0.60754

Table 9. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.57 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 4.4432 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
34031387- 1	3.9152	287.43	46.25	25.581	1.5317	1380200	0.6069	0.6077
34031387- 2	3.9159	288.27	46.11	25.465	1.5243	1370800	0.6063	0.6071
34031387- 3	4.1161	289.67	48.22	4.066	0.6233	557300	0.6075	0.6077
34031387- 4	4.1236	289.73	48.30	3.610	0.6036	539600	0.6074	0.6075
34031387- 5	3.7970	286.47	45.02	48.299	2.0759	1877700	0.6061	0.6076
34031387- 6	3.7983	287.86	44.79	48.189	2.0685	1864600	0.6061	0.6076
34110387- 1	3.7591	289.56	44.04	49.297	2.0651	1854700	0.6033	0.6048
34110387- 2	3.7631	289.20	44.15	49.162	2.0653	1856400	0.6034	0.6050
34110387- 3	3.8977	287.11	46.10	30.523	1.6647	1501400	0.6047	0.6057
34110387- 4	3.8769	288.09	45.68	30.697	1.6620	1495800	0.6048	0.6057
34110387- 5	3.9699	288.73	46.67	12.580	1.0761	966000	0.6058	0.6061
34110387- 6	3.9737	288.78	46.71	12.631	1.0800	969300	0.6065	0.6068
34110387- 7	4.1152	289.67	48.21	4.094	0.6265	560100	0.6086	0.6087
34110387- 8	4.1150	289.67	48.21	4.443	0.6520	582900	0.6079	0.6081
34110487- 1	3.6980	287.94	43.59	47.444	2.0242	1826400	0.6059	0.6075
34110487- 2	3.6952	287.99	43.55	47.255	2.0184	1821100	0.6057	0.6072
34110487- 3	3.8870	288.84	45.67	12.850	1.0791	969300	0.6075	0.6079
34110487- 4	3.8868	289.05	45.63	13.062	1.0865	975600	0.6070	0.6074
34110487- 5	4.0239	289.91	47.09	4.231	0.6293	562900	0.6084	0.6085
34110487- 6	4.0343	289.57	47.28	4.062	0.6185	553600	0.6091	0.6092
34110487- 7	3.8236	287.77	45.11	26.854	1.5491	1396200	0.6066	0.6075
34110487- 8	3.8303	287.78	45.19	26.693	1.5461	1393300	0.6067	0.6076
34110487- 9	3.6888	287.28	43.59	49.405	2.0678	1868900	0.6065	0.6081

Table 10. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.65 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 5.0780 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
06/24/87- 1	299.58	2.579	3.133	58997	0.61699
06/24/87- 2	299.64	2.620	3.158	59542	0.61709
06/24/87- 3	299.70	2.534	3.108	58687	0.61759
06/24/87- 4	299.78	7.323	5.257	99454	0.61449
06/24/87- 5	299.84	7.034	5.156	97651	0.61482
06/24/87- 6	299.87	7.006	5.145	97523	0.61487
06/24/87- 7	299.94	20.928	8.858	168145	0.61245
06/24/87- 8	299.97	21.258	8.927	169560	0.61240
06/24/87- 9	299.99	21.282	8.930	169699	0.61229
06/24/87-10	300.07	69.105	16.036	305257	0.61017
06/24/87-11	300.08	69.037	16.038	305369	0.61055
06/24/87-12	300.09	69.038	16.037	305421	0.61053
06/24/87-13	300.13	69.139	16.053	306045	0.61067
06/24/87-14	300.15	68.565	15.985	304884	0.61063
06/24/87-15	300.16	69.306	16.072	306597	0.61064
06/24/87-16	300.23	192.670	26.740	510891	0.60936
06/24/87-17	300.24	192.548	26.738	510956	0.60950
06/24/87-18	300.26	192.555	26.743	511277	0.60961
06/25/87-19	299.87	2.563	3.122	59175	0.61688
06/25/87-20	299.92	2.569	3.127	59328	0.61699
06/25/87-21	299.97	2.561	3.123	59321	0.61723
06/25/87-22	300.12	6.948	5.121	97616	0.61455
06/25/87-23	300.16	6.966	5.130	97857	0.61476
06/25/87-24	300.20	6.940	5.119	97744	0.61469
06/25/87-25	300.29	21.162	8.904	170328	0.61222
06/25/87-26	300.33	21.172	8.905	170496	0.61215
06/25/87-27	300.36	21.178	8.909	170694	0.61238
06/25/87-28	300.43	68.890	16.021	307413	0.61058
06/25/87-29	300.44	68.686	15.993	306950	0.61043
06/25/87-30	300.45	69.129	16.049	308080	0.61058
06/25/87-31	300.50	69.160	16.053	308496	0.61062
06/25/87-32	300.52	68.982	16.034	308264	0.61069
06/25/87-33	300.53	69.014	16.028	308272	0.61029
06/25/87-34	300.62	192.258	26.720	514905	0.60958
06/25/87-35	300.61	192.308	26.724	514868	0.60958
06/25/87-36	300.61	192.646	26.746	515299	0.60956

Table 11. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.65 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 5.0780 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
35102687- 1	3.9139	288.99	45.96	9.288	1.2576	1128200	0.6091	0.6093
35102687- 2	3.9095	288.67	45.97	9.266	1.2541	1126100	0.6081	0.6084
35102687- 3	4.0613	287.36	48.00	2.879	0.7182	645700	0.6116	0.6117
35102687- 4	4.0585	287.86	47.87	3.056	0.7389	663600	0.6116	0.6117
35102687- 5	3.6432	278.97	44.47	31.679	2.2656	2090100	0.6035	0.6045
35102687- 6	3.6498	276.91	44.92	31.379	2.2644	2099700	0.6031	0.6040
35102687- 7	3.8027	285.32	45.29	19.732	1.8072	1638000	0.6047	0.6053
35102687- 8	3.8036	289.76	44.53	20.202	1.8132	1625800	0.6046	0.6052
35102887- 1	4.0884	286.48	48.48	2.840	0.7171	645900	0.6118	0.6119
35102887- 2	4.1002	286.49	48.62	2.529	0.6756	608400	0.6100	0.6100
35102887- 3	3.8875	289.14	45.63	18.309	1.7525	1572000	0.6065	0.6070
35102887- 4	3.8675	287.35	45.70	18.400	1.7528	1579600	0.6046	0.6051
35102887- 5	3.6830	282.47	44.34	30.973	2.2331	2041200	0.6025	0.6034
35102887- 6	3.6789	281.44	44.47	30.589	2.2251	2039100	0.6032	0.6041
35102887- 7	3.9204	288.88	46.06	9.902	1.2971	1163900	0.6078	0.6081
35102887- 8	3.9257	291.05	45.74	10.274	1.3170	1175600	0.6079	0.6082

Table 12. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.65 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 5.0780 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
06/29/87- 1	300.68	2.558	3.119	60276	0.61698
06/29/87- 2	300.75	2.621	3.158	61104	0.61686
06/29/87- 3	300.79	2.624	3.159	61179	0.61683
06/29/87- 4	300.91	7.088	5.171	100411	0.61437
06/29/87- 5	300.94	7.081	5.170	100463	0.61445
06/29/87- 6	300.98	7.088	5.172	100590	0.61443
06/29/87- 7	301.07	20.707	8.806	171610	0.61211
06/29/87- 8	301.09	20.695	8.804	171653	0.61218
06/29/87- 9	301.11	20.711	8.808	171794	0.61219
06/29/87-10	301.17	69.177	16.050	313429	0.61036
06/29/87-11	301.19	68.940	16.027	313112	0.61053
06/29/87-12	301.20	69.089	16.039	313427	0.61035
06/29/87-13	301.28	68.941	16.026	313698	0.61050
06/29/87-14	301.27	69.192	16.056	314213	0.61053
06/29/87-15	301.28	69.286	16.066	314486	0.61051
06/29/87-16	301.37	192.642	26.744	524627	0.60950
06/29/87-17	301.38	192.955	26.757	524981	0.60929
06/29/87-18	301.39	193.394	26.794	525810	0.60943
06/30/87-19	300.90	2.616	3.152	61183	0.61630
06/30/87-20	300.95	2.618	3.153	61286	0.61634
06/30/87-21	301.00	2.610	3.150	61292	0.61670
06/30/87-22	301.08	7.034	5.154	100459	0.61466
06/30/87-23	301.12	7.021	5.148	100432	0.61456
06/30/87-24	301.16	7.019	5.150	100544	0.61483
06/30/87-25	301.24	20.846	8.838	172849	0.61227
06/30/87-26	301.27	20.851	8.837	172950	0.61217
06/30/87-27	301.29	20.826	8.831	172900	0.61209
06/30/87-28	301.39	69.019	16.034	314666	0.61050
06/30/87-29	301.40	69.106	16.043	314910	0.61045
06/30/87-30	301.42	69.167	16.047	315125	0.61034
06/30/87-31	301.49	69.217	16.059	315818	0.61056
06/30/87-32	301.50	69.260	16.063	315968	0.61053
06/30/87-33	301.50	69.280	16.067	316037	0.61058
06/30/87-34	301.54	193.164	26.774	527105	0.60937
06/30/87-35	301.52	193.039	26.772	526836	0.60951
06/30/87-36	301.50	193.459	26.800	527166	0.60948

Table 13. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.65 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 5.0780 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
35102887- 1	3.8647	286.71	45.78	17.504	1.7150	1548500	0.6060	0.6065
35102887- 2	3.8717	286.62	45.88	17.380	1.7089	1543100	0.6053	0.6058
35102887- 3	3.9568	290.52	46.20	8.599	1.2133	1084300	0.6091	0.6093
35102887- 4	3.9384	290.73	45.95	8.649	1.2117	1082600	0.6082	0.6084
35102887- 5	4.0855	291.40	47.55	2.639	0.6834	608500	0.6106	0.6107
35102887- 6	4.0955	290.63	47.80	2.958	0.7268	648300	0.6117	0.6118
35102887- 7	3.7050	283.79	44.38	30.070	2.2161	2019100	0.6064	0.6073
35102887- 8	3.6974	283.14	44.40	29.798	2.1976	2005700	0.6040	0.6049
35102987- 1	3.6909	287.95	43.51	31.066	2.2353	2016300	0.6077	0.6086
35102987- 2	3.7134	286.81	43.96	29.671	2.1939	1983900	0.6072	0.6080
35102987- 3	3.9489	288.13	46.53	10.300	1.3364	1201300	0.6108	0.6111
35102987- 4	3.9341	288.20	46.34	10.380	1.3369	1201700	0.6099	0.6102
35102987- 5	3.8459	287.46	45.43	18.746	1.7744	1599500	0.6081	0.6086
35102987- 6	3.8488	287.64	45.43	18.652	1.7658	1591000	0.6067	0 6072
35102987- 7	4.0805	288.38	48.04	2.677	0.6912	620000	0.6102	0.6103
35102987- 8	4.0840	288.73	48.02	2.747	0.7003	627600	0.6104	0.6104
35103087- 1	3.7126	288.02	43.75	29.402	2.1652	1952200	0.6034	0.6043
35103087- 2	3.7174	287.96	43.82	29.477	2.1709	1957600	0.6038	0.6046
35103087- 3	3.9386	287.91	46.45	9.497	1.2741	1146100	0.6070	0.6073
35103087- 4	3.9271	288.04	46.29	9.599	1.2797	1150900	0.6075	0.6077
35103087- 5	3.8529	287.63	45.48	18.317	1.7431	1570500	0.6040	0.6045
35103087- 6	3.8462	287.65	45.40	18.129	1.7336	1562100	0.6044	0.6049
35103087- 8	4.0740	289.02	47.85	2.870	0.7141	639600	0.6100	0.6101

Table 14. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.65 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 5.0780 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
07/13/87- 1	302.15	2.494	3.081	61475	0.61702
07/13/87- 2	302.18	2.497	3.085	61604	0.61749
07/13/87- 3	302.21	2.484	3.077	61486	0.61750
07/13/87- 4	302.26	7.004	5.143	102881	0.61463
07/13/87- 5	302.29	7.019	5.147	103042	0.61454
07/13/87- 6	302.33	7.015	5.147	103118	0.61467
07/13/87- 7	302.36	20.959	8.864	177693	0.61238
07/13/87- 8	302.39	20.949	8.861	177761	0.61237
07/13/87- 9	302.40	20.888	8.850	177570	0.61248
07/13/87-10	302.46	69.180	16.066	322757	0.61097
07/13/87-11	302.47	68.965	16.044	322383	0.61108
07/13/87-12	302.48	68.978	16.047	322514	0.61115
07/13/87-13	302.53	69.148	16.069	323305	0.61125
07/13/87-14	302.55	69.367	16.097	323994	0.61133
07/13/87-15	302.55	69.471	16.107	324203	0.61127
07/13/87-16	302.61	193.393	26.848	541073	0.61068
07/13/87-17	302.61	193.337	26.847	541045	0.61073
07/13/87-18	302.63	193.280	26.843	541193	0.61074
07/14/87-19	302.10	2.543	3.103	61851	0.61535
07/14/87-20	302.15	2.526	3.093	61723	0.61559
07/14/87-21	302.20	2.507	3.083	61584	0.61585
07/14/87-22	302.27	2.486	3.070	61436	0.61589
07/14/87-23	302.31	2.488	3.071	61499	0.61584
07/14/87-24	302.35	2.482	3.068	61502	0.61601
07/14/87-25	302.46	6.973	5.128	103025	0.61428
07/14/87-26	302.48	6.993	5.136	103227	0.61432
07/14/87-27	302.51	6.981	5.132	103210	0.61440
07/14/87-28	302.78	20.838	8.838	178781	0.61241
07/14/87-29	302.81	20.833	8.835	178830	0.61227
07/14/87-30	302.82	20.790	8.828	178734	0.61245
07/14/87-31	302.89	69.099	16.057	325573	0.61104
07/14/87-32	302.88	68.864	16.034	325032	0.61119
07/14/87-33	302.89	68.996	16.045	325328	0.61104
07/14/87-34	303.05	68.849	16.036	326231	0.61136
07/14/87-35	303.05	69.053	16.061	326722	0.61137
07/14/87-36	303.06	68.876	16.042	326410	0.61145
07/14/87-37	303.13	191.549	26.723	544538	0.61078
07/14/87-38	303.14	192.371	26.781	545844	0.61081
07/14/87-39	303.15	192.531	26.798	546298	0.61094

Table 15. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.65 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 5.0780 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
35031387- 1	4.1351	288.36	48.68	3.254	0.7667	687500	0.6097	0.6098
35031387- 2	4.1387	288.09	48.78	3.199	0.7651	686500	0.6130	0.6131
35031387- 3	4.1421	288.44	48.75	3.104	0.7546	676500	0.6140	0.6140
35031387- 4	3.7025	285.66	44.03	32.321	2.2883	2076200	0.6062	0.6071
35031387- 5	3.7040	286.03	43.98	32.062	2.2827	2069200	0.6075	0.6084
35031387- 6	3.8884	289.54	45.57	20.129	1.8432	1653100	0.6085	0.6091
35031387- 7	3.8878	289.24	45.61	20.183	1.8485	1659000	0.6091	0.6097
35110387- 1	3.9744	288.58	46.75	9.039	1.2554	1127200	0.6109	0.6112
35110387- 2	3.9625	287.64	46.78	8.912	1.2442	1119900	0.6097	0.6099
35110387- 3	3.7055	288.69	43.56	30.695	2.2235	2002400	0.6077	0.6086
35110387- 4	3.6926	288.06	43.51	30.414	2.2121	1995500	0.6077	0.6086
35110387- 5	4.1068	288.58	48.31	3.029	0.7392	662700	0.6116	0.6117
35110387- 6	4.0998	288.87	48.17	2.721	0.7019	628900	0.6136	0.6137
35110387- 7	3.8575	287.37	45.58	18.417	1.7710	1597100	0.6112	0.6118
35110387- 8	3.8608	287.16	45.66	18.294	1.7643	1591900	0.6105	0.6110
35110387- 9	3.9700	287.66	46.86	9.176	1.2694	1142400	0.6125	0.6127
35110387-10	3.9495	287.81	46.59	8.937	1.2510	1125700	0.6134	0.6136
35110687- 1	3.7047	287.74	43.70	28.680	2.1579	1947800	0.6092	0.6100
35110687- 2	3.6998	287.82	43.63	28.697	2.1537	1943700	0.6083	0.6091
35110687- 3	3.8248	287.61	45.15	19.229	1.7922	1616000	0.6082	0.6088
35110687- 4	3.8282	287.72	45.17	19.176	1.7897	1613200	0.6081	0.6086
35110687- 5	3.9166	288.56	46.07	9.348	1.2654	1137100	0.6100	0.6102
35110687- 6	3.9195	288.61	46.09	9.457	1.2725	1143300	0.6097	0.6100
35110687- 7	4.0616	288.68	47.76	2.824	0.7136	639900	0.6149	0.6150
35110687- 8	4.0738	288.79	47.88	2.702	0.6984	626000	0.6145	0.6146
35110687- 9	3.7140	288.31	43.72	29.026	2.1711	1956800	0.6091	0.6100

Table 16. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.73 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 5.7132 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
06/22/87- 1	297.52	2.547	4.230	76022	0.61740
06/22/87- 2	297.57	2.541	4.226	76047	0.61761
06/22/87- 3	297.62	2.542	4.226	76142	0.61742
06/22/87- 4	297.76	20.922	12.012	217092	0.61170
06/22/87- 5	297.77	21.195	12.085	218458	0.61144
06/22/87- 6	297.80	21.004	12.031	217624	0.61145
06/22/87- 7	297.95	7.066	7.012	127292	0.61447
06/22/87- 8	297.99	7.115	7.037	127855	0.61452
06/22/87- 9	298.02	7.077	7.017	127575	0.61440
06/22/87-10	298.10	20.961	12.019	218921	0.61153
06/22/87-11	298.13	21.140	12.077	220113	0.61184
06/22/87-12	298.16	20.800	11.978	218455	0.61178
06/22/87-13	298.27	69.366	21.796	398490	0.60961
06/22/87-14	298.28	70.138	21.900	400575	0.60915
06/22/87-15	298.31	69.124	21.788	398780	0.61045
06/22/87-16	298.46	192.474	36.205	664857	0.60792
06/22/87-17	298.47	192.478	36.213	665147	0.60804
06/22/87-18	298.47	192.747	36.234	665524	0.60796
06/23/87-19	298.53	2.579	4.256	78278	0.61737
06/23/87-20	298.58	2.596	4.270	78616	0.61729
06/23/87-21	298.63	2.616	4.285	78984	0.61715
06/23/87-22	298.78	6.976	6.968	128886	0.61454
06/23/87-23	298.82	7.013	6.986	129327	0.61452
06/23/87-24	298.84	7.028	6.992	129508	0.61443
06/23/87-25	299.31	20.759	11.964	223923	0.61173
06/23/87-26	299.31	20.769	11.963	223903	0.61152
06/23/87-27	299.34	20.866	11.993	224616	0.61164
06/23/87-28	299.41	21.190	12.088	226792	0.61177
06/23/87-29	299.42	21.276	12.109	227231	0.61159
06/23/87-30	299.43	21.171	12.078	226711	0.61156
06/23/87-31	299.87	69.293	21.771	412641	0.60933
06/23/87-32	299.90	69.299	21.778	413054	0.60952
06/23/87-33	299.93	69.397	21.783	413421	0.60924
06/23/87-34	300.03	192.080	36.159	687721	0.60786
06/23/87-35	300.03	194.617	36.398	692272	0.60788
06/23/87-36	300.03	192.240	36.182	688167	0.60800

Table 17. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.73 Beta Ratio, 0.89 μm Roughness

Pipe Diameter = 7.816 cm Orifice Diameter = 5.7132 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
36042787- 1	3.8189	287.15	45.16	11.538	1.8650	1682800	0.6021	0.6024
36042787- 2	3.8276	288.01	45.11	11.573	1.8701	1683600	0.6031	0.6034
36042787- 3	4.0476	288.81	47.57	2.935	0.9727	871800	0.6070	0.6070
36042787- 4	4.0666	289.12	47.74	2.942	0.9768	874500	0.6076	0.6077
36042787- 5	3.7299	288.36	43.90	17.487	2.2617	2036900	0.6014	0.6019
36042787- 6	3.7025	288.26	43.59	18.183	2.2981	2070800	0.6014	0.6018
36042787- 7	3.9325	287.86	46.38	6.673	1.4478	1302300	0.6066	0.6068
36042787- 8	3.9630	287.52	46.81	6.712	1.4603	1314100	0.6073	0.6075
36042787- 9	3.9290	288.37	46.25	6.695	1.4454	1298600	0.6054	0.6056
36042987- 1	3.7103	284.93	44.24	18.089	2.3112	2099400	0.6019	0.6024
36042987- 2	3.6997	285.42	44.04	18.013	2.3028	2089500	0.6024	0.6029
36042987- 3	3.9315	286.82	46.55	6.974	1.4798	1334400	0.6054	0.6055
36042987- 4	3.9430	287.01	46.66	6.457	1.4315	1290100	0.6079	0.6081
36042987- 5	3.9664	287.83	46.79	6.505	1.4331	1288700	0.6056	0.6057
36042987- 6	4.0760	288.75	47.92	2.769	0.9511	852300	0.6088	0.6089
36042987- 7	4.0765	288.68	47.94	2.755	0.9512	852500	0.6103	0.6104
36042987- 8	3.8729	288.69	45.53	12.147	1.9324	1735900	0.6055	0.6058
36042987- 9	3.8779	288.21	45.67	12.104	1.9319	1737400	0.6055	0.6058
36111087- 1	3.8886	288.29	45.79	6.404	1.4040	1262000	0.6044	0.6046
36111087- 2	3.8738	288.27	45.61	6.351	1.3960	1255200	0.6047	0.6048
36111087- 3	3.6582	288.22	43.08	17.021	2.2169	1998600	0.6033	0.6037
36111087- 4	3.6580	287.55	43.18	16.899	2.2076	1993400	0.6022	0.6026
36111087- 5	4.0095	289.72	46.96	2.955	0.9703	868000	0.6074	0.6075
36111087- 6	4.0047	289.98	46.86	3.036	0.9826	878400	0.6074	0.6075
36111087- 7	3.7803	288.81	44.42	12.087	1.8973	1705500	0.6035	0.6038
36111087- 8	3.8027	289.13	44.63	12.013	1.8956	1702200	0.6034	0.6037
36111287- 1	3.8704	288.76	45.49	5.772	1.3303	1194700	0.6053	0.6054
36111287- 2	3.8916	288.73	45.75	5.824	1.3419	1204900	0.6061	0.6062
36111287- 3	3.9675	289.28	46.54	2.650	0.9151	819900	0.6076	0.6076
36111287- 4	3.9720	289.27	46.60	2.676	0.9214	825500	0.6084	0.6085
36111287- 5	3.7580	288.03	44.29	11.885	1.8787	1692400	0.6035	0.6038
36111287- 6	3.7692	288.28	44.38	11.771	1.8680	1681500	0.6024	0.6027
36111287- 7	3.6386	288.73	42.76	17.054	2.2050	1985800	0.6017	0.6021
36111287- 8	3.6362	287.94	42.86	16.792	2.1896	1975700	0.6014	0.6019

Table 18. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.73 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 5.7132 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
06/26/87- 1	301.40	2.573	4.242	83258	0.61603
06/26/87- 2	301.45	2.588	4.256	83628	0.61635
06/26/87- 3	301.52	2.596	4.261	83860	0.61621
06/26/87- 4	301.58	6.968	6.948	136907	0.61323
06/26/87- 5	301.61	7.023	6.978	137583	0.61346
06/26/87- 6	301.65	7.021	6.976	137657	0.61335
06/26/87- 7	301.71	21.106	12.043	237954	0.61073
06/26/87- 8	301.72	21.391	12.127	239645	0.61083
06/26/87- 9	301.75	21.207	12.068	238645	0.61052
06/26/87-10	301.81	21.122	12.052	238678	0.61095
06/26/87-11	301.83	21.106	12.045	238642	0.61082
06/26/87-12	301.86	20.928	11.998	237854	0.61101
06/26/87-13	301.89	69.536	21.788	432206	0.60871
06/26/87-14	301.89	69.214	21.739	431241	0.60877
06/26/87-15	301.89	69.179	21.731	431082	0.60870
06/26/87-16	301.97	192.651	36.182	718961	0.60732
06/26/87-17	301.98	192.441	36.169	718863	0.60744
06/26/87-18	301.98	192.630	36.182	719124	0.60737
06/29/87-19	299.80	2.541	4.216	79898	0.61607
06/29/87-20	299.85	2.531	4.210	79867	0.61635
06/29/87-21	299.91	2.544	4.222	80198	0.61651
06/29/87-22	300.00	6.984	6.965	132570	0.61390
06/29/87-23	300.04	7.057	7.001	133367	0.61384
06/29/87-24	300.07	7.070	7.007	133569	0.61384
06/29/87-25	300.27	21.165	12.064	231013	0.61084
06/29/87-26	300.29	21.098	12.050	230846	0.61111
06/29/87-27	300.31	21.175	12.071	231338	0.61102
06/29/87-28	300.38	21.184	12.077	231798	0.61120
06/29/87-29	300.40	21.308	12.112	232568	0.61118
06/29/87-30	300.41	21.100	12.055	231531	0.61131
06/29/87-31	300.47	69.234	21.748	418228	0.60883
06/29/87-32	300.49	69.126	21.736	418177	0.60897
06/29/87-33	300.52	69.415	21.785	419388	0.60907
06/29/87-34	300.59	192.838	36.227	698615	0.60769
06/29/87-35	300.59	192.595	36.207	698235	0.60774
06/29/87-36	300.57	192.957	36.227	698316	0.60750

Table 19. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.73 Beta Ratio, 4.1 μm Roughness

Pipe Diameter = 7.813 cm Orifice Diameter = 5.7132 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
36031087- 1	4.0521	288.23	47.73	2.434	0.8913	799900	0.6097	0.6097
36031087- 2	4.0318	288.20	47.50	2.432	0.8860	795500	0.6078	0.6078
36031087- 3	4.0398	288.26	47.58	2.431	0.8874	796500	0.6083	0.6084
36031087- 4	3.9315	287.55	46.42	9.197	1.7013	1531600	0.6068	0.6070
36031087- 5	3.9319	286.70	46.58	9.152	1.6947	1528800	0.6049	0.6051
36031087- 6	3.9310	287.38	46.45	9.164	1.6940	1525700	0.6051	0.6053
36031087- 7	3.6634	285.50	43.59	19.762	2.4059	2183900	0.6039	0.6044
36031087- 8	3.6650	287.49	43.28	19.728	2.3920	2160700	0.6031	0.6036
36031787- 1	4.0674	288.84	47.80	2.736	0.9455	847200	0.6096	0.6096
36031787- 2	4.0709	288.76	47.86	2.700	0.9412	843500	0.6105	0.6105
36031787- 3	3.7199	284.38	44.46	17.746	2.2947	2087200	0.6019	0.6024
36031787- 4	3.7180	285.20	44.29	17.810	2.2925	2081100	0.6014	0.6018
36031787- 5	3.8986	289.48	45.70	9.800	1.7307	1551500	0.6027	0.6029
36031787- 6	3.9381	288.89	46.27	9.819	1.7491	1569400	0.6047	0.6050
36110987- 1	3.7108	289.63	43.46	16.566	2.1947	1971200	0.6025	0.6029
36110987- 2	3.7205	289.47	43.61	16.477	2.1914	1968800	0.6023	0.6027
36110987- 3	3.8271	289.49	44.85	12.401	1.9306	1732200	0.6032	0.6035
36110987- 4	3.8218	288.52	44.96	12.295	1.9235	1730000	0.6029	0.6031
36110987- 5	4.0578	288.12	47.82	2.576	0.9152	821600	0.6079	0.6079
36110987- 6	4.0323	288.17	47.51	2.586	0.9147	821300	0.6084	0.6084
36110987- 7	3.9199	287.58	46.28	6.535	1.4287	1286400	0.6055	0.6056
36110987- 8	3.9261	287.57	46.36	6.499	1.4254	1283400	0.6053	0.6054
36111087- 1	4.0037	288.83	47.05	2.844	0.9535	855000	0.6076	0.6077
36111087- 2	3.9954	288.81	46.96	2.838	0.9524	854300	0.6082	0.6083
36111087- 3	3.7776	287.81	44.56	11.797	1.8757	1690800	0.6028	0.6031
36111087- 4	3.7767	287.54	44.59	11.640	1.8610	1678700	0.6019	0.6022
36111087- 5	3.6454	288.93	42.81	17.111	2.2094	1989300	0.6014	0.6018
36111087- 6	3.6549	284.12	43.72	16.901	2.2184	2020800	0.6013	0.6017
36111087- 7	3.8914	287.34	45.99	6.388	1.4094	1270200	0.6061	0.6063
36111087- 8	3.8813	287.96	45.76	6.528	1.4169	1275200	0.6043	0.6044

Table 20. Measured and Calculated Quantities Using Water in the 3-Inch Orifice Meter, 0.73 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 5.7132 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
07/14/87- 1	303.10	2.516	4.195	85417	0.61606
07/14/87- 2	303.13	2.541	4.217	85937	0.61635
07/14/87- 3	303.16	2.519	4.202	85672	0.61673
07/14/87- 4	303.23	7.016	6.981	142583	0.61400
07/14/87- 5	303.24	7.007	6.977	142524	0.61399
07/14/87- 6	303.26	7.019	6.982	142688	0.61390
07/14/87- 7	303.30	20.970	12.023	245915	0.61162
07/14/87- 8	303.32	21.005	12.029	246147	0.61144
07/14/87- 9	303.33	20.943	12.013	245873	0.61153
07/14/87-10	303.38	20.950	12.018	246213	0.61165
07/14/87-11	303.39	20.879	12.000	245898	0.61178
07/14/87-12	303.40	20.402	11.863	243143	0.61183
07/14/87-13	303.43	69.207	21.796	447005	0.61034
07/14/87-14	303.43	69.304	21.807	447242	0.61024
07/14/87-15	303.43	69.337	21.815	447396	0.61030
07/14/87-16	303.53	193.177	36.379	747642	0.60976
07/14/87-17	303.53	193.011	36.367	747386	0.60981
07/14/87-18	303.54	192.869	36.360	747404	0.60992
07/15/87-19	302.89	2.544	4.226	85689	0.61717
07/15/87-20	302.93	2.532	4.217	85570	0.61732
07/15/87-21	302.96	2.534	4.220	85685	0.61756
07/15/87-22	303.07	6.993	6.975	141948	0.61438
07/15/87-23	303.08	6.969	6.960	141686	0.61419
07/15/87-24	303.11	6.953	6.955	141657	0.61439
07/15/87-25	303.18	20.830	11.988	244525	0.61185
07/15/87-26	303.19	20.791	11.971	244242	0.61159
07/15/87-27	303.19	20.738	11.962	244096	0.61187
07/15/87-28	303.27	20.739	11.962	244518	0.61190
07/15/87-29	303.28	20.654	11.939	244087	0.61196
07/15/87-30	303.30	20.698	11.952	244455	0.61199
07/15/87-31	303.58	69.267	21.803	448545	0.61029
07/15/87-32	303.59	69.333	21.823	449058	0.61057
07/15/87-33	303.62	69.280	21.806	448983	0.61032
07/15/87-34	303.64	68.892	21.743	447881	0.61029
07/15/87-35	303.66	69.070	21.774	448698	0.61036
07/15/87-36	303.68	69.064	21.774	448878	0.61038
07/15/87-37	303.76	192.866	36.360	750977	0.60995
07/15/87-38	303.75	192.445	36.315	749888	0.60985
07/15/87-39	303.75	193.222	36.391	751453	0.60990

Table 21. Measured and Calculated Quantities Using Nitrogen Gas in the 3-Inch Orifice Meter, 0.73 Beta Ratio, 7.6 μm Roughness

Pipe Diameter = 7.811 cm Orifice Diameter = 5.7132 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
36031287- 1	3.9148	286.86	46.35	9.166	1.7085	1541700	0.6107	0.6109
36031287- 2	3.9157	286.36	46.45	9.109	1.7022	1537900	0.6097	0.6099
36031287- 3	3.6973	288.33	43.52	18.586	2.3504	2118900	0.6086	0.6091
36031287- 4	3.6975	288.78	43.45	18.470	2.3376	2105100	0.6077	0.6082
36031287- 6	4.1506	288.52	48.84	2.814	0.9735	872500	0.6120	0.6121
36032687- 1	3.6969	284.79	44.11	18.442	2.3581	2144300	0.6089	0.6094
36032687- 2	3.6791	283.74	44.08	18.196	2.3393	2133200	0.6084	0.6089
36032687- 3	4.1043	288.45	48.31	2.694	0.9490	851100	0.6131	0.6132
36032687- 4	4.0921	288.51	48.15	2.700	0.9510	853000	0.6147	0.6148
36032687- 5	3.9983	287.45	47.24	6.432	1.4514	1306500	0.6136	0.6137
36032687- 6	4.0082	287.96	47.26	6.390	1.4461	1300000	0.6132	0.6133
36032687- 7	3.8735	287.64	45.72	11.362	1.8925	1705400	0.6117	0.6119
36032687- 8	3.8753	287.29	45.80	11.322	1.8900	1704500	0.6114	0.6117
36110487- 1	3.7007	286.96	43.79	12.443	1.9177	1734400	0.6052	0.6055
36110487- 2	3.7076	287.31	43.81	12.533	1.9301	1744000	0.6068	0.6071
36110487- 3	3.7001	287.27	43.73	12.478	1.9232	1738000	0.6065	0.6068
36110487- 4	3.8130	287.53	45.02	6.824	1.4465	1304700	0.6081	0.6083
36110487- 5	3.8053	287.64	44.91	6.893	1.4499	1307500	0.6072	0.6074
36110487- 6	3.8640	288.41	45.47	2.712	0.9173	825100	0.6087	0.6088
36110487- 7	3.8751	288.44	45.60	2.672	0.9111	819400	0.6083	0.6083
36110487- 8	3.6278	288.04	42.75	16.578	2.1907	1977800	0.6061	0.6065
36110487- 9	3.6291	283.83	43.46	16.182	2.1820	1990300	0.6061	0.6065
36110587- 1	3.8903	287.24	45.99	7.019	1.4847	1338800	0.6089	0.6090
36110587- 2	3.8494	287.24	45.51	7.064	1.4808	1336000	0.6086	0.6087
36110587- 3	3.7731	286.83	44.67	12.019	1.9091	1725600	0.6070	0.6073
36110587- 4	3.7923	287.13	44.85	12.053	1.9136	1728000	0.6063	0.6066
36110587- 5	4.0277	288.12	47.46	2.767	0.9467	850500	0.6088	0.6089
36110587- 6	4.0294	288.22	47.46	2.761	0.9493	852600	0.6112	0.6113
36110587- 7	4.0236	288.27	47.39	2.762	0.9478	851200	0.6106	0.6107
36110587- 8	3.6737	288.21	43.26	16.519	2.2049	1988700	0.6075	0.6079
36110587- 9	3.6888	288.22	43.44	16.193	2.1866	1971800	0.6072	0.6077
36101686- 1	3.9275	288.09	46.28	9.055	1.7025	1531500	0.6127	0.6129
36101686- 2	3.9268	288.46	46.21	9.055	1.6971	1525300	0.6112	0.6114
36101686- 3	3.6728	285.42	43.71	20.150	2.4630	2236900	0.6111	0.6117
36101686- 4	3.6735	283.96	43.97	19.906	2.4499	2232900	0.6098	0.6103
36101686- 5	4.0229	288.67	47.31	2.620	0.9208	826200	0.6097	0.6097
36101686- 6	4.0278	288.98	47.31	2.682	0.9316	835300	0.6096	0.6097
36102186- 1	3.9843	291.27	46.39	8.646	1.6565	1477800	0.6093	0.6095
36102186- 2	3.9820	290.30	46.53	8.602	1.6547	1479700	0.6093	0.6095
36102186- 3	4.0718	290.97	47.46	2.472	0.8991	801900	0.6117	0.6118
36102186- 4	4.0563	290.07	47.45	2.465	0.8961	801100	0.6107	0.6108
36102186- 5	3.7099	282.58	44.65	19.429	2.4376	2228400	0.6096	0.6101
36102186- 6	3.7088	285.94	44.06	19.508	2.4221	2195900	0.6084	0.6089

Table 22. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.43 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 10.368 cm Orifice Diameter = 4.4445 cm

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

Table 23. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.43 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 4.4445 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43072386- 1	4.1317	288.73	48.58	3.703	0.5731	386900	0.6057	0.6058
43072386- 2	4.1166	288.77	48.39	3.430	0.5490	370600	0.6040	0.6041
43072386- 3	3.9910	287.92	47.07	18.442	1.2517	848100	0.6016	0.6022
43072386- 4	3.9948	287.86	47.12	18.483	1.2533	849200	0.6013	0.6019
43072386- 5	3.8380	287.28	45.36	49.536	2.0170	1371200	0.6013	0.6029
43072386- 6	3.8390	287.43	45.35	49.035	1.9990	1358400	0.5991	0.6007
43072386- 7	3.8387	287.36	45.36	48.923	2.0028	1361300	0.6009	0.6025
43072486- 1	4.0088	287.73	47.31	17.820	1.2369	838200	0.6032	0.6038
43072486- 2	4.0081	287.75	47.30	17.866	1.2374	838600	0.6028	0.6033
43072486- 3	4.1653	288.66	48.99	3.349	0.5475	369500	0.6059	0.6060
43072486- 4	4.1627	288.91	48.91	3.179	0.5336	359900	0.6067	0.6068
43072486- 5	3.8528	287.76	45.46	47.933	1.9894	1350600	0.6023	0.6039
43072486- 6	3.8535	287.46	45.52	47.591	1.9793	1344800	0.6011	0.6026
43073186- 1	4.0625	289.97	47.54	3.197	0.5260	354300	0.6047	0.6048
43073186- 3	3.7344	288.11	43.99	50.528	2.0100	1365400	0.6024	0.6041
43073186- 4	3.7345	288.28	43.97	49.997	1.9941	1354100	0.6010	0.6027
43073186- 5	3.8833	288.73	45.65	20.484	1.2963	877700	0.6001	0.6007

Table 24. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.43 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 4.4445 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
43072286- 1	3.9996	287.93	47.16	17.766	1.2336	834700	0.6034	0.6040
43072286- 2	3.9990	287.93	47.16	17.714	1.2307	832700	0.6029	0.6035
43072286- 3	3.8380	287.43	45.34	47.456	1.9715	1338100	0.6007	0.6023
43072286- 4	3.8375	287.41	45.33	47.072	1.9617	1331500	0.6002	0.6018
43072286- 5	4.1268	288.71	48.52	3.264	0.5375	362400	0.6054	0.6055
43072286- 6	4.1307	288.69	48.57	3.916	0.5882	396700	0.6046	0.6047
43072586- 1	3.8296	287.68	45.20	46.843	1.9558	1326800	0.6008	0.6024
43072586- 2	3.8293	287.51	45.22	46.645	1.9495	1323100	0.6000	0.6015
43072586- 3	3.9688	287.78	46.83	20.359	1.3101	887100	0.6007	0.6014
43072586- 4	3.9679	287.84	46.80	20.528	1.3160	890900	0.6010	0.6017
43072586- 5	4.1648	288.87	48.94	2.895	0.5068	341500	0.6040	0.6041
43080586- 1	3.9463	288.13	46.50	19.464	1.2802	866300	0.6025	0.6031
43080586- 2	3.9457	288.17	46.48	19.551	1.2799	866100	0.6011	0.6018
43080586- 3	4.1434	289.25	48.62	3.121	0.5255	353800	0.6054	0.6054
43080586- 4	4.1093	289.34	48.20	3.063	0.5181	348900	0.6048	0.6049
43080586- 5	3.8034	287.48	44.92	50.328	2.0209	1372100	0.6006	0.6023
43080586- 6	3.8031	287.73	44.87	49.976	2.0090	1363200	0.5995	0.6012

Table 25. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.55 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 10.368 cm Orifice Diameter = 5.7137 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/19/87- 1	301.18	2.545	3.699	54454	0.60888
03/19/87- 2	301.23	2.522	3.684	54289	0.60913
03/19/87- 3	301.32	20.791	10.526	155409	0.60620
03/19/87- 4	301.34	20.785	10.521	155437	0.60601
03/19/87- 5	301.41	21.033	10.590	156698	0.60642
03/19/87- 6	301.43	21.173	10.627	157304	0.60650
03/19/87- 7	301.47	69.627	19.221	284772	0.60495
03/19/87- 8	301.48	69.475	19.197	284470	0.60484
03/19/87- 9	301.58	193.140	31.967	474706	0.60408
03/19/87-10	301.59	192.893	31.939	474387	0.60393
03/20/87-11	302.56	2.554	3.709	56248	0.60951
03/20/87-12	302.61	2.527	3.691	56033	0.60982
03/20/87-13	302.70	21.242	10.641	161895	0.60645
03/20/87-14	302.71	21.451	10.692	162700	0.60636
03/20/87-15	302.79	21.034	10.590	161415	0.60649
03/20/87-16	302.80	21.178	10.627	162010	0.60654
03/20/87-17	302.84	69.057	19.136	291976	0.60484
03/20/87-18	302.85	69.246	19.165	292469	0.60491
03/20/87-19	302.88	192.659	31.918	487403	0.60399
03/20/87-20	302.89	192.984	31.945	487927	0.60400

Table 26. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.55 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 10.368 cm Orifice Diameter = 5.7137 cm

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

Table 27. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.55 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 5.7137 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/17/87- 1	299.81	2.523	3.687	52683	0.60942
03/17/87- 2	299.87	2.549	3.708	53042	0.60976
03/17/87- 3	300.13	20.930	10.563	152004	0.60623
03/17/87- 4	300.15	20.898	10.558	151998	0.60641
03/17/87- 5	300.24	20.861	10.553	152227	0.60670
03/17/87- 6	300.27	20.758	10.526	151938	0.60665
03/17/87- 7	300.30	69.084	19.156	276663	0.60513
03/17/87- 8	300.32	69.082	19.155	276781	0.60514
03/17/87- 9	300.37	192.768	31.948	462124	0.60420
03/17/87-10	300.38	192.984	31.957	462354	0.60403
03/18/87-11	301.71	2.530	3.693	54998	0.60971
03/18/87-12	301.75	2.566	3.718	55411	0.60947
03/18/87-13	301.82	20.999	10.580	157969	0.60632
03/18/87-14	301.83	20.960	10.564	157763	0.60597
03/18/87-15	301.92	20.889	10.556	157947	0.60656
03/18/87-16	301.94	20.907	10.560	158071	0.60652
03/18/87-17	301.96	69.539	19.207	287626	0.60489
03/18/87-18	301.97	69.541	19.213	287773	0.60506
03/18/87-19	301.99	192.607	31.916	478252	0.60396
03/18/87-20	301.99	192.637	31.918	478279	0.60394

Table 28. Measured and calculated quantitites using Nitrogen Gas in the 4-Inch Orifice Meter, 0.55 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 5.7137 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44082086- 1	3.9906	287.26	47.18	8.942	1.4902	1011300	0.6027	0.6030
44082086- 2	3.9890	287.27	47.16	8.912	1.4876	1009500	0.6028	0.6031
44082086- 3	4.1199	287.74	48.62	2.473	0.7974	539700	0.6044	0.6045
44082086- 4	4.1307	287.68	48.76	2.443	0.7921	536100	0.6031	0.6032
44082086- 5	3.7333	286.70	44.22	24.983	2.4156	1646600	0.6032	0.6040
44082086- 6	3.7242	286.71	44.11	24.547	2.3839	1625100	0.6013	0.6021
44062687- 1	3.8786	286.48	45.99	14.855	1.8915	1287700	0.6010	0.6014
44062687- 2	3.8785	286.72	45.94	14.798	1.8871	1284000	0.6010	0.6015
44062687- 5	4.0509	289.34	47.51	4.288	1.0387	700900	0.6047	0.6048
44062687- 6	4.0523	289.38	47.52	4.277	1.0371	699700	0.6044	0.6046
44062687- 7	3.7461	288.85	44.01	22.762	2.2913	1553500	0.6009	0.6016
44062687- 8	3.7372	288.49	43.96	22.629	2.2827	1549100	0.6007	0.6014
44062687-10	4.0423	293.23	46.72	2.966	0.8575	573400	0.6053	0.6054

Table 29. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.55 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 5.7137 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/12/87- 1	299.08	2.510	3.684	51719	0.61060
03/12/87- 2	299.12	2.509	3.684	51766	0.61079
03/12/87- 5	299.37	20.642	10.498	148337	0.60678
03/12/87- 6	299.38	20.624	10.493	148301	0.60676
03/12/87- 7	299.55	69.590	19.232	272880	0.60544
03/12/87- 8	299.58	69.568	19.234	273078	0.60559
03/12/87- 9	299.63	192.586	31.954	454173	0.60469
03/12/87-10	299.64	192.552	31.959	454349	0.60485
03/16/87-11	299.92	2.548	3.708	53040	0.61008
03/16/87-12	299.97	2.503	3.677	52651	0.61033
03/16/87-13	300.03	2.523	3.692	52935	0.61043
03/16/87-14	300.07	2.515	3.687	52916	0.61059
03/16/87-15	300.15	20.777	10.528	151383	0.60661
03/16/87-16	300.17	20.745	10.521	151355	0.60670
03/16/87-17	300.08	20.644	10.501	150733	0.60698
03/16/87-18	300.14	20.402	10.438	150061	0.60694
03/16/87-19	300.22	69.285	19.189	276337	0.60546
03/16/87-20	300.26	68.713	19.107	275390	0.60538
03/16/87-21	300.35	193.004	31.983	461867	0.60464
03/16/87-22	300.35	193.277	32.009	462239	0.60470

Table 30. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.55 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 5.7137 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44051387- 1	3.9310	288.38	46.27	7.340	1.3387	905600	0.6036	0.6038
44051387- 2	3.9468	288.62	46.42	7.358	1.3420	907100	0.6034	0.6036
44051387- 4	3.7112	288.77	43.61	23.013	2.2936	1554100	0.6010	0.6018
44051387- 5	4.0685	288.62	47.85	3.121	0.8924	602400	0.6070	0.6071
44051387- 7	3.8902	286.53	46.12	14.927	1.9044	1294600	0.6029	0.6034
44051387- 8	3.8881	289.60	45.55	15.050	1.8999	1282000	0.6026	0.6031
44051587- 3	3.7089	287.49	43.80	23.853	2.3471	1595300	0.6029	0.6036
44051587- 4	3.7141	288.13	43.75	23.867	2.3447	1591000	0.6023	0.6031
44051587- 5	4.0959	287.59	48.37	2.846	0.8544	577900	0.6053	0.6054
44051587- 6	4.0911	287.64	48.30	2.833	0.8530	576900	0.6061	0.6062
44051587- 7	3.8962	289.59	45.65	14.785	1.8869	1273200	0.6033	0.6037
44051587- 8	3.9157	289.96	45.82	14.773	1.8863	1271400	0.6022	0.6026
44062487- 1	3.7043	287.23	43.78	23.311	2.3213	1578800	0.6032	0.6040
44062487- 2	3.7115	288.01	43.74	23.351	2.3231	1576900	0.6035	0.6042
44062487- 3	3.8584	288.13	45.46	14.871	1.8925	1282100	0.6046	0.6050
44062487- 4	3.9528	287.31	46.72	7.651	1.3800	935600	0.6065	0.6067
44062487- 5	3.7250	286.40	44.17	22.700	2.3020	1568500	0.6036	0.6043
44062487- 6	3.8617	285.07	46.04	14.911	1.9060	1300800	0.6043	0.6048
44062487- 7	3.9561	286.10	46.98	7.641	1.3789	937600	0.6047	0.6050

Table 31. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.67 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 4.082 cm Orifice Diameter = 6.9840 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/19/87- 1	301.85	2.521	5.931	88603	0.61420
03/19/87- 2	301.88	2.519	5.931	88654	0.61438
03/19/87- 3	301.96	21.338	17.106	256114	0.60881
03/19/87- 4	301.98	21.281	17.083	255887	0.60883
03/19/87- 5	302.04	21.080	17.012	255137	0.60917
03/19/87- 6	302.05	21.304	17.109	256659	0.60945
03/19/87- 7	302.04	68.708	30.611	459103	0.60716
03/19/87- 8	302.04	68.523	30.562	458359	0.60700
03/19/87- 9	302.07	192.383	51.099	766854	0.60570
03/19/87-10	302.07	192.383	51.106	766971	0.60579
03/20/87-11	302.23	2.529	5.935	89386	0.61357
03/20/87-12	302.27	2.529	5.936	89470	0.61361
03/20/87-13	302.35	21.226	17.058	257564	0.60877
03/20/87-14	302.37	21.244	17.062	257732	0.60864
03/20/87-15	302.43	21.250	17.084	258390	0.60935
03/20/87-16	302.44	21.039	16.989	257008	0.60899
03/20/87-17	302.45	69.297	30.741	465138	0.60718
03/20/87-18	302.46	69.557	30.804	466181	0.60728
03/20/87-19	302.49	192.449	51.105	773908	0.60570
03/20/87-20	302.48	192.462	51.110	773811	0.60573

Table 32. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.67 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 10.368 cm Orifice Diameter = 6.9840 cm

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

Table 33. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.67 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 6.9840 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/17/87- 1	300.53	2.521	5.937	86188	0.61464
03/17/87- 2	300.56	2.518	5.934	86208	0.61477
03/17/87- 3	300.67	20.756	16.890	245938	0.60936
03/17/87- 4	300.68	20.727	16.878	245808	0.60935
03/17/87- 5	300.72	20.807	16.926	246733	0.60994
03/17/87- 6	300.75	20.600	16.840	245633	0.60986
03/17/87- 7	300.78	69.358	30.797	449500	0.60784
03/17/87- 8	300.79	69.443	30.817	449892	0.60787
03/17/87- 9	300.82	192.906	51.269	748934	0.60675
03/17/87-10	300.83	195.208	51.556	753300	0.60655
03/17/87-11	300.82	192.629	51.214	748142	0.60654
03/17/87-12	300.82	192.474	51.218	748201	0.60683
03/18/87-13	301.51	2.498	5.905	87573	0.61418
03/18/87-14	301.55	2.509	5.920	87863	0.61436
03/18/87-15	301.62	20.920	16.954	252017	0.60933
03/18/87-16	301.65	20.791	16.897	251324	0.60916
03/18/87-17	301.69	21.064	17.016	253319	0.60949
03/18/87-18	301.71	20.969	16.987	252989	0.60981
03/18/87-19	301.71	69.174	30.742	457848	0.60763
03/18/87-20	301.71	68.988	30.698	457187	0.60757
03/18/87-21	301.74	192.807	51.224	763372	0.60644
03/18/87-22	301.73	192.751	51.226	763249	0.60656

Table 34. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.67 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 6.9840 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45082086- 1	4.0073	287.77	47.28	2.570	1.2823	868900	0.6052	0.6053
45082086- 2	4.0055	287.59	47.29	2.556	1.2814	868700	0.6063	0.6063
45082086- 3	3.9813	287.69	46.99	5.123	1.8085	1226100	0.6062	0.6063
45082086- 4	3.9800	286.78	47.14	5.139	1.8121	1231300	0.6056	0.6057
45082086- 5	3.7469	286.96	44.34	9.573	2.3999	1634500	0.6057	0.6060
45082086- 6	3.7527	286.98	44.40	9.487	2.3865	1625200	0.6047	0.6049
45082986- 1	3.9426	287.86	46.50	5.064	1.7806	1207200	0.6035	0.6036
45082986- 2	3.9424	287.73	46.52	5.069	1.7856	1211000	0.6047	0.6049
45082986- 3	4.0134	287.73	47.36	2.612	1.2985	879900	0.6072	0.6072
45082986- 4	4.0128	288.59	47.20	2.624	1.2954	876000	0.6054	0.6055
45082986- 5	3.7090	287.06	43.87	10.116	2.4473	1667200	0.6040	0.6043
45082986- 6	3.7108	287.37	43.84	10.081	2.4443	1663900	0.6046	0.6049

Table 35. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.67 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 6.9840 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/12/87- 2	299.81	2.554	5.978	85299	0.61524
03/12/87- 3	299.86	2.553	5.978	85392	0.61533
03/12/87- 6	299.99	20.923	16.966	243076	0.61000
03/12/87- 7	300.02	20.917	16.966	243240	0.61010
03/12/87-11	300.14	21.070	17.034	244847	0.61033
03/12/87-12	300.15	20.982	17.001	244416	0.61040
03/12/87-13	300.17	69.408	30.840	443579	0.60882
03/12/87-14	300.19	69.428	30.850	443912	0.60893
03/12/87-15	300.29	192.450	51.291	739786	0.60809
03/12/87-16	300.29	192.872	51.364	740838	0.60828
03/13/87-19	300.39	2.491	5.894	85192	0.61418
03/13/87-20	300.42	2.542	5.951	86081	0.61389
03/13/87-21	300.50	2.532	5.941	86078	0.61407
03/13/87-22	300.54	2.544	5.956	86363	0.61411
03/13/87-23	300.59	21.406	17.146	248897	0.60952
03/13/87-24	300.60	21.290	17.107	248380	0.60979
03/13/87-25	300.63	21.402	17.146	249160	0.60958
03/13/87-26	300.63	21.433	17.160	249371	0.60965
03/13/87-27	300.69	21.281	17.111	248974	0.61007
03/13/87-28	300.70	21.101	17.036	247938	0.60999
03/13/87-29	300.77	69.260	30.782	448653	0.60836
03/13/87-30	300.78	69.250	30.776	448669	0.60829
03/13/87-31	300.84	192.963	51.330	749267	0.60778
03/13/87-32	300.87	194.527	51.526	752604	0.60764

Table 36. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.67 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 6.9840 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45051387- 1	3.9132	289.53	45.86	4.778	1.7372	1172100	0.6107	0.6108
45051387- 2	3.9077	288.91	45.91	4.758	1.7310	1169700	0.6095	0.6097
45051387- 3	3.7166	284.77	44.35	9.320	2.3741	1624200	0.6076	0.6079
45051387- 4	3.7166	285.50	44.23	9.333	2.3770	1623300	0.6088	0.6091
45051387- 5	3.9798	285.36	47.40	2.757	1.3348	909000	0.6079	0.6080
45051387- 6	3.9617	289.52	46.43	2.803	1.3403	903800	0.6114	0.6115
45051387- 7	3.9679	289.34	46.54	2.801	1.3389	903200	0.6104	0.6105
45051387- 8	3.8749	289.48	45.42	6.608	2.0263	1367900	0.6086	0.6088
45051387- 9	3.8521	288.94	45.24	6.566	2.0137	1361600	0.6080	0.6081
45051587- 3	3.7358	288.02	44.03	9.059	2.3222	1575900	0.6050	0.6053
45051587- 4	3.9593	287.28	46.80	2.843	1.3397	908300	0.6046	0.6046
45051587- 5	3.9743	287.92	46.87	2.865	1.3525	915500	0.6075	0.6076
45051587- 6	3.9376	287.28	46.55	4.531	1.6931	1148300	0.6068	0.6069
45051587- 7	3.9544	287.17	46.76	4.536	1.6998	1152800	0.6074	0.6075
45051587- 8	3.8633	288.08	45.52	6.725	2.0353	1378900	0.6053	0.6055
45051587- 9	3.8533	286.56	45.67	6.651	2.0297	1380300	0.6061	0.6062
45051587-10	3.9807	287.55	47.01	2.623	1.2939	876500	0.6065	0.6066
45062487- 1	3.9151	288.96	45.98	4.396	1.6590	1120900	0.6072	0.6073
45062487- 2	3.9004	288.89	45.82	4.378	1.6528	1117100	0.6073	0.6075
45062487- 3	3.6979	284.51	44.17	9.397	2.3654	1619700	0.6041	0.6044
45062487- 4	3.6941	285.11	44.02	9.394	2.3658	1617700	0.6054	0.6056
45062487- 5	3.9809	285.09	47.46	2.584	1.2934	881300	0.6080	0.6080
45062487- 6	3.9661	285.19	47.27	2.581	1.2896	878700	0.6077	0.6078
45062487- 7	3.8419	287.96	45.29	6.723	2.0359	1380000	0.6071	0.6073
45062487- 8	3.8444	288.13	45.29	6.723	2.0348	1378700	0.6068	0.6070

Table 37. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.73 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 10.368 cm Orifice Diameter = 7.6177 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/19/87- 1	302.16	2.531	7.481	112481	0.61383
03/19/87- 2	302.19	2.523	7.466	112332	0.61358
03/19/87- 3	302.25	20.852	21.277	320581	0.60823
03/19/87- 4	302.27	20.804	21.259	320458	0.60845
03/19/87- 5	302.30	20.538	21.127	318667	0.60858
03/19/87- 6	302.33	21.178	21.454	323800	0.60858
03/19/87- 7	302.31	69.307	38.659	583220	0.60619
03/19/87- 8	302.30	69.304	38.657	583074	0.60618
03/19/87- 9	302.39	193.219	64.328	972104	0.60412
03/19/87-10	302.41	192.550	64.240	971183	0.60435
03/20/87-11	301.60	2.538	7.497	111369	0.61419
03/20/87-12	301.65	2.529	7.488	111353	0.61452
03/20/87-13	301.72	21.229	21.469	319761	0.60824
03/20/87-14	301.74	21.281	21.488	320179	0.60804
03/20/87-15	301.78	21.163	21.454	320012	0.60877
03/20/87-16	301.80	20.761	21.248	317058	0.60870
03/20/87-17	301.83	68.726	38.503	574908	0.60626
03/20/87-18	301.84	68.630	38.472	574576	0.60620
03/20/87-19	301.94	192.573	64.232	961315	0.60420
03/20/87-20	302.00	192.652	64.273	963145	0.60447

Table 38. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.73 Beta Ratio, 0.76 μm Roughness

Pipe Diameter = 10.368 cm Orifice Diameter = 7.6177 cm

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

Table 39. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.73 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 7.6177 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/17/87- 1	301.11	2.544	7.516	110499	0.61492
03/17/87- 2	301.13	2.529	7.494	110228	0.61502
03/17/87- 3	301.21	20.883	21.326	314199	0.60904
03/17/87- 4	301.22	20.934	21.338	314435	0.60863
03/17/87- 5	301.27	20.882	21.316	314446	0.60876
03/17/87- 6	301.28	20.636	21.197	312758	0.60896
03/17/87- 7	301.31	68.779	38.561	569326	0.60681
03/17/87- 8	301.31	68.797	38.558	569289	0.60669
03/17/87- 9	301.36	192.639	64.390	951893	0.60546
03/17/87-10	301.39	192.632	64.384	952412	0.60542
03/18/87-11	301.03	2.517	7.468	109597	0.61431
03/18/87-12	301.06	2.510	7.464	109617	0.61478
03/18/87-13	301.14	20.651	21.203	311919	0.60891
03/18/87-14	301.17	20.763	21.247	312771	0.60854
03/18/87-15	301.20	21.047	21.396	315165	0.60865
03/18/87-16	301.22	21.053	21.406	315448	0.60886
03/18/87-17	301.26	69.279	38.672	570365	0.60636
03/18/87-18	301.27	69.323	38.715	571118	0.60684
03/18/87-19	301.34	192.556	64.353	950944	0.60524
03/18/87-20	301.36	192.340	64.339	951146	0.60546

Table 40. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.73 Beta Ratio, 3.8 μm Roughness

Pipe Diameter = 10.366 cm Orifice Diameter = 7.6177 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46072386- 2	3.7209	286.89	44.04	5.809	2.3379	1593100	0.6036	0.6037
46072386- 3	3.7206	286.87	44.04	5.773	2.3339	1590500	0.6044	0.6046
46072386- 4	3.8311	287.15	45.31	4.347	2.0455	1391100	0.6019	0.6020
46072386- 5	3.8304	287.14	45.30	4.360	2.0515	1395200	0.6028	0.6029
46072386- 6	3.9614	287.52	46.78	2.416	1.5561	1055700	0.6045	0.6046
46072386- 7	3.9615	287.56	46.78	2.434	1.5648	1061500	0.6057	0.6057
46072486- 1	3.9703	288.08	46.79	2.336	1.5340	1039200	0.6060	0.6060
46072486- 2	3.9679	287.79	46.81	2.319	1.5233	1032700	0.6038	0.6039
46072486- 3	3.8556	287.42	45.55	4.276	2.0406	1386500	0.6039	0.6040
46072486- 4	3.8560	287.31	45.57	4.256	2.0318	1380900	0.6024	0.6025
46072486- 5	3.6757	286.67	43.54	6.299	2.4190	1650100	0.6032	0.6033
46072486- 6	3.6754	286.97	43.49	6.314	2.4137	1645300	0.6015	0.6016
46073186- 1	3.7684	288.94	44.26	4.406	2.0421	1383800	0.6038	0.6040
46073186- 2	3.7706	288.81	44.30	4.398	2.0421	1384300	0.6040	0.6042
46073186- 3	3.5701	288.50	41.99	6.645	2.4421	1660500	0.6037	0.6038
46073186- 4	3.5831	287.90	42.24	6.621	2.4357	1658300	0.6014	0.6015
46073186- 5	3.8447	289.00	45.15	2.586	1.5791	1068900	0.6035	0.6036
46073186- 6	3.8535	288.97	45.25	2.618	1.5907	1076800	0.6035	0.6036

Table 41. Measured and Calculated Quantities Using Water in the 4-Inch Orifice Meter, 0.73 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 7.6177 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
03/13/87- 1	299.87	2.572	7.543	107761	0.61436
03/13/87- 2	299.91	2.563	7.526	107648	0.61404
03/13/87- 3	300.05	20.772	21.268	305106	0.60953
03/13/87- 4	300.06	20.796	21.283	305395	0.60962
03/13/87- 5	300.15	20.765	21.270	305796	0.60971
03/13/87- 6	300.16	20.857	21.322	306601	0.60984
03/13/87- 7	300.16	69.110	38.708	556616	0.60820
03/13/87- 8	300.17	69.422	38.803	558108	0.60833
03/13/87- 9	300.20	69.383	38.787	558239	0.60825
03/13/87-10	300.22	69.056	38.699	557210	0.60831
03/13/87-11	300.37	193.046	64.618	933603	0.60751
03/13/87-12	300.41	193.085	64.630	934585	0.60757
03/16/87-13	299.25	2.510	7.448	104955	0.61402
03/16/87-14	299.25	2.520	7.464	105179	0.61405
03/16/87-15	299.44	21.014	21.356	302266	0.60848
03/16/87-16	299.44	21.339	21.529	304718	0.60873
03/16/87-17	300.22	20.635	21.166	304806	0.60864
03/16/87-18	300.26	20.795	21.256	306358	0.60885
03/16/87-19	300.32	69.017	38.622	557377	0.60727
03/16/87-20	300.33	68.917	38.576	556826	0.60697
03/16/87-21	300.42	193.242	64.576	933947	0.60681
03/16/87-22	300.43	193.714	64.655	935283	0.60681

Table 42. Measured and Calculated Quantities Using Nitrogen Gas in the 4-Inch Orifice Meter, 0.73 Beta Ratio, 6.9 μm Roughness

Pipe Diameter = 10.378 cm Orifice Diameter = 7.6177 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46072286- 1	3.7047	287.44	43.75	5.750	2.3256	1580900	0.6060	0.6061
46072286- 2	3.7044	287.36	43.77	5.677	2.3127	1572500	0.6064	0.6066
46072286- 3	3.9026	287.72	46.05	2.450	1.5651	1060800	0.6091	0.6092
46072286- 4	3.9017	287.58	46.07	2.482	1.5749	1067700	0.6089	0.6090
46072286- 5	3.8105	287.24	45.04	4.351	2.0560	1396600	0.6071	0.6072
46072286- 6	3.8089	287.26	45.02	4.327	2.0508	1393000	0.6074	0.6075
46072586- 1	3.8897	288.22	45.81	4.117	2.0226	1369300	0.6088	0.6089
46072586- 2	3.8895	287.78	45.89	4.075	2.0119	1363600	0.6082	0.6083
46072586- 3	3.9876	287.83	47.04	2.398	1.5649	1059300	0.6092	0.6092
46072586- 4	3.9871	287.80	47.04	2.407	1.5619	1057300	0.6069	0.6069
46072586- 5	3.6867	286.92	43.63	5.984	2.3781	1619000	0.6084	0.6085
46080586- 1	3.8302	287.84	45.17	4.320	2.0529	1392100	0.6074	0.6075
46080586- 2	3.8298	287.93	45.15	4.316	2.0479	1388500	0.6064	0.6065
46080586- 3	3.9250	288.28	46.22	2.487	1.5725	1064000	0.6063	0.6064
46080586- 4	3.9246	288.19	46.23	2.483	1.5741	1065400	0.6074	0.6075
46080586- 5	3.6139	287.61	42.65	6.828	2.5085	1706400	0.6076	0.6077
46080586- 6	3.6136	287.16	42.72	6.706	2.4886	1694800	0.6077	0.6079

Table 43. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.49 Beta Ratio, 2.8 μm Roughness

Pipe Diameter = 15.563 cm Orifice Diameter = 7.7026 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/18/87- 1	297.99	2.571	6.620	60406	0.60688
02/18/87- 2	298.01	2.567	6.617	60410	0.60706
02/18/87- 3	298.04	2.569	6.617	60451	0.60691
02/18/87- 4	298.16	21.192	18.937	173456	0.60469
02/18/87- 5	298.17	21.102	18.893	173134	0.60458
02/18/87- 6	298.18	21.331	18.992	174079	0.60449
02/18/87- 7	298.23	129.042	46.598	427581	0.60300
02/18/87- 8	298.23	129.154	46.621	427790	0.60304
02/18/87- 9	298.24	129.343	46.638	428038	0.60281
02/18/87-10	299.26	2.516	6.543	61447	0.60642
02/18/87-11	299.29	2.520	6.547	61528	0.60635
02/18/87-12	299.32	2.512	6.541	61513	0.60678
02/18/87-13	299.43	21.081	18.875	177920	0.60438
02/18/87-14	299.46	20.854	18.770	177053	0.60430
02/18/87-15	299.47	21.179	18.918	178485	0.60437
02/18/87-16	299.46	129.300	46.623	439772	0.60280
02/18/87-17	299.47	129.439	46.640	440025	0.60270
02/18/87-18	299.48	129.332	46.624	439972	0.60274

Table 44. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.49 Beta Ratio, 5.1 μm Roughness

Pipe Diameter = 15.433 cm Orifice Diameter = 7.7026 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/24/87- 1	298.82	2.544	6.585	61758	0.60625
02/24/87- 2	298.83	2.540	6.581	61742	0.60631
02/24/87- 5	299.15	21.086	18.912	178679	0.60482
02/24/87- 6	299.18	21.066	18.902	178707	0.60480
02/24/87- 7	299.20	128.984	46.650	441324	0.60321
02/24/87- 8	299.21	129.277	46.699	441889	0.60317
02/25/87-10	299.94	2.535	6.579	63272	0.60680
02/25/87-11	299.98	2.535	6.577	63312	0.60672
02/25/87-13	300.11	20.974	18.856	182014	0.60470
02/25/87-14	300.12	21.088	18.910	182579	0.60482
02/25/87-15	300.14	128.879	46.613	450231	0.60304
02/25/87-16	300.50	128.954	46.628	453970	0.60309

Table 45. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.49 Beta Ratio, 8.9 μm Roughness

Pipe Diameter = 15.573 cm Orifice Diameter = 7.7026 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/27/87- 1	301.21	2.497	6.521	64423	0.60684
02/27/87- 2	301.25	2.490	6.513	64399	0.60705
02/27/87- 7	301.42	20.913	18.797	186564	0.60449
02/27/87- 8	301.44	20.895	18.797	186647	0.60476
02/27/87-11	301.68	128.523	46.510	464159	0.60335
02/27/87-12	301.68	128.547	46.521	464270	0.60344
03/02/87-13	300.76	2.495	6.512	63703	0.60618
03/02/87-14	300.80	2.492	6.507	63710	0.60617
03/02/87-17	300.99	21.058	18.858	185430	0.60433
03/02/87-18	301.02	20.960	18.822	185198	0.60459
03/02/87-21	301.21	128.443	46.484	459212	0.60317
03/02/87-22	301.22	128.417	46.483	459299	0.60322

Table 46. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.57 Beta Ratio, 2.8 μm Roughness

Pipe Diameter = 15.563 cm Orifice Diameter = 8.7808 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/13/87- 1	3.5291	286.32	43.47	2.473	1.7953	825000	0.6064
11/13/87- 2	3.5321	281.76	44.29	17.324	4.7868	2227000	0.6048
11/13/87- 3	3.5293	278.04	44.92	47.989	8.0322	3776000	0.6045
11/13/87- 4	3.5287	276.93	45.11	48.005	8.0508	3797000	0.6046
11/13/87- 5	3.5288	277.09	45.08	17.078	4.7890	2257000	0.6042
11/13/87- 6	3.5310	278.65	44.84	2.561	1.8520	869000	0.6055
11/13/87- 7	3.5299	278.98	44.76	2.557	1.8493	867000	0.6056
11/25/87- 1	3.5286	273.43	45.75	50.973	8.3588	3982000	0.6048
11/25/87- 2	3.5275	270.48	46.29	92.174	11.3271	5442000	0.6045
11/25/87- 3	3.5277	268.43	46.69	149.168	14.5159	7016000	0.6045
11/25/87- 4	3.5284	267.32	46.93	149.292	14.5571	7060000	0.6044
11/25/87- 5	3.5280	266.04	47.17	93.142	11.4868	5591000	0.6042
11/25/87- 6	3.5282	265.65	47.25	47.901	8.2195	4006000	0.6039

Table 47. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.57 Beta Ratio, 5.1 μm Roughness

Pipe Diameter = 15.433 cm Orifice Diameter = 8.7808 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/16/87- 1	3.5286	280.15	44.53	2.474	1.8166	856000	0.6052
11/16/87- 2	3.5265	275.87	45.27	18.168	4.9614	2367000	0.6044
11/16/87- 3	3.5278	271.76	46.05	46.549	8.0318	3877000	0.6051
11/16/87- 4	3.5284	270.65	46.28	46.535	8.0476	3897000	0.6050
11/16/87- 5	3.5284	270.43	46.33	17.828	4.9668	2407000	0.6040
11/16/87- 6	3.5274	272.48	45.92	2.398	1.8148	874000	0.6049
11/16/87- 7	3.5282	273.32	45.76	2.399	1.8116	871000	0.6047
11/25/87- 1	3.5295	270.98	46.13	102.422	11.9826	5796000	0.6056
11/25/87- 2	3.5289	268.48	46.71	149.836	14.6007	7115000	0.6054
11/25/87- 3	3.5291	267.21	46.97	149.877	14.6411	7162000	0.6054
11/25/87- 4	3.5295	265.98	47.21	93.103	11.5267	5659000	0.6051
11/25/87- 5	3.5280	265.71	47.24	41.418	7.6644	3766000	0.6048

Table 48. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.57 Beta Ratio, 8.9 μm Roughness

Pipe Diameter = 15.573 cm Orifice Diameter = 8.7808 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/16/87- 1	3.5281	285.15	43.67	2.385	1.7667	814000	0.6066
11/16/87- 2	3.5280	280.54	44.45	18.085	4.9142	2293000	0.6067
11/16/87- 3	3.5279	275.82	45.30	46.598	7.9791	3773000	0.6070
11/16/87- 4	3.5284	274.15	45.62	46.604	8.0059	3803000	0.6069
11/16/87- 5	3.5280	273.71	45.70	18.091	4.9750	2367000	0.6059
11/16/87- 6	3.5278	275.09	45.43	2.627	1.8847	893000	0.6045
11/25/87- 1	3.5291	273.65	45.72	48.625	8.1951	3899000	0.6075
11/25/87- 2	3.5286	270.54	46.29	92.483	11.3956	5470000	0.6072
11/25/87- 3	3.5279	268.43	46.69	148.535	14.5517	7028000	0.6074
11/25/87- 4	3.5294	267.15	46.97	148.608	15.0461	7075000	0.6072
11/25/87- 5	3.5288	265.93	47.21	92.192	11.4804	5587000	0.6069

Table 49. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.66 Beta Ratio, 2.8 μm Roughness

Pipe Diameter = 15.563 cm Orifice Diameter = 10.3215 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/17/87- 1	297.90	2.550	12.854	117061	0.61032
02/17/87- 2	297.45	2.554	12.852	115826	0.60981
02/17/87- 3	297.47	2.553	12.857	115922	0.61018
02/17/87- 4	297.51	21.141	36.766	331869	0.60630
02/17/87- 5	297.51	21.136	36.765	331857	0.60636
02/17/87- 6	297.52	21.131	36.752	331812	0.60622
02/17/87- 7	297.75	162.444	101.450	920640	0.60356
02/17/87- 8	297.83	162.207	101.349	921367	0.60341
02/17/87- 9	297.90	162.087	101.322	922749	0.60347
02/18/87-13	298.59	2.517	12.769	118132	0.61043
02/18/87-14	298.61	2.522	12.794	118413	0.61093
02/18/87-15	298.62	2.515	12.762	118141	0.61031
02/18/87-19	298.70	21.656	37.210	345058	0.60636
02/18/87-20	298.71	21.690	37.245	345456	0.60645
02/18/87-21	298.73	21.727	37.256	345713	0.60612
02/18/87-22	298.98	163.982	101.875	950742	0.60332
02/18/87-23	299.05	163.720	101.757	951090	0.60311
02/18/87-24	299.12	164.194	101.935	954205	0.60329

Table 50. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.66 Beta Ratio, 2.8 μm Roughness

Pipe Diameter = 15.563 cm Orifice Diameter = 10.3215 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/13/87- 1	3.5295	278.26	44.88	2.456	2.6376	1239000	0.6035
11/13/87- 2	3.5288	274.04	45.64	22.346	7.9950	3802000	0.6008
11/13/87- 3	3.5290	270.37	46.34	56.858	12.8643	6182000	0.6005
11/13/87- 4	3.5303	269.65	46.50	56.572	12.8553	6192000	0.6006
11/13/87- 5	3.5305	269.76	46.47	22.396	8.0703	3885000	0.6004
11/13/87- 6	3.5305	271.71	46.10	2.628	2.7538	1318000	0.6011
11/30/87- 1	3.5266	264.65	47.43	121.137	19.0114	9293000	0.5991
11/30/87- 2	3.5169	258.82	48.52	188.655	24.1588	12021000	0.6011
11/30/87- 3	3.5282	257.04	49.06	189.216	24.3262	12171000	0.6011
11/30/87- 4	3.5228	254.82	49.47	118.629	19.2432	9694000	0.6002
11/30/87- 5	3.5298	253.65	49.83	54.979	13.1106	6630000	0.6005

Table 51. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.66 Beta Ratio, 5.1 μm Roughness

Pipe Diameter = 15.433 cm Orifice Diameter = 10.3215 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/20/87 -1	300.43	2.519	12.833	124751	0.61072
02/20/87 -2	300.45	2.520	12.841	124887	0.61103
02/20/87 -3	300.52	21.163	36.960	359995	0.60689
02/20/87 -4	300.54	21.269	37.046	360990	0.60679
02/20/87 -5	300.69	163.509	102.235	999618	0.60396
02/20/87 -6	300.77	162.935	102.030	999311	0.60381
02/24/87 -9	299.45	2.517	12.838	122117	0.61122
02/24/87-10	299.47	2.514	12.836	122151	0.61149
02/24/87-11	299.52	20.719	36.558	348269	0.60663
02/24/87-12	299.53	20.727	36.566	348417	0.60664
02/24/87-15	300.08	162.827	102.035	984283	0.60400
02/24/87-16	300.15	162.847	102.083	986224	0.60424

Table 52. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.66 Beta Ratio, 5.1 μm Roughness

Pipe Diameter = 15.433 cm Orifice Diameter = 10.3215 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/16/87- 1	3.5282	278.59	44.80	2.486	2.6603	1259000	0.6029
11/16/87- 2	3.5282	273.04	45.83	21.668	7.9483	3822000	0.6029
11/16/87- 3	3.5276	269.26	46.53	57.551	13.0671	6354000	0.6025
11/16/87- 4	3.5279	267.76	46.84	57.591	13.1075	6401000	0.6023
11/16/87- 5	3.5278	267.04	46.97	21.853	8.0730	3951000	0.6024
11/16/87- 6	3.5277	269.71	46.45	2.417	2.6685	1296000	0.6026
12/01/87- 1	3.5227	270.37	46.25	115.825	18.5025	8967000	0.6014
12/01/87- 2	3.5271	264.15	47.54	185.607	23.8576	11778000	0.6022
12/01/87- 3	3.5294	261.48	48.12	185.704	24.0032	11945000	0.6021
12/01/87- 4	3.5246	259.09	48.57	111.001	18.5129	9280000	0.6003
12/01/87- 5	3.5273	258.15	48.81	56.894	13.2739	6674000	0.6013

Table 53. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.66 Beta Ratio, 8.9 μm Roughness

Pipe Diameter = 15.573 cm Orifice Diemeter = 10.3215 cm

Run ID	Temperature (K)	Dif Press (kPe)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/26/87- 1	301.19	2.513	12.744	125843	0.60999
02/26/87- 2	301.20	2.503	12.731	125746	0.61058
02/26/87- 5	301.34	20.996	36.660	363160	0.60708
02/26/87- 6	301.34	20.945	36.619	362758	0.60715
02/26/87- 7	301.52	162.443	101.730	1011822	0.60566
02/26/87- 8	301.59	162.102	101.631	1012335	0.60571
03/02/87-11	300.21	2.505	12.732	123046	0.61031
03/02/87-12	300.23	2.502	12.726	123036	0.61043
03/02/87-13	300.28	20.887	36.579	354114	0.60724
03/02/87-14	300.29	20.911	36.575	354151	0.60684
03/02/87-17	300.55	163.367	102.005	993218	0.60551
03/02/87-18	300.64	163.874	102.166	996918	0.60554

Table 54. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.66 Beta Ratio, 8.9 μm Roughness

Pipe Diameter = 15.573 cm Orifice Diameter = 10.3215 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/16/87- 1	3.5277	281.37	44.31	2.416	2.6036	1212000	0.6046
11/16/87- 2	3.5272	275.43	45.36	22.891	8.1379	3852000	0.6062
11/16/87- 3	3.5275	270.76	46.25	58.147	13.1111	6290000	0.6059
11/16/87- 4	3.5275	269.32	46.52	58.209	13.1506	6336000	0.6056
11/16/87- 5	3.5275	269.48	46.49	22.739	8.2000	3949000	0.6056
11/16/87- 6	3.5277	273.37	45.75	2.600	2.7383	1304000	0.6033
12/01/87- 1	3.5259	270.65	46.25	113.431	18.3850	8823000	0.6066
12/01/87- 2	3.5258	264.82	47.38	186.306	23.9597	11698000	0.6072
12/01/87- 3	3.5256	262.54	47.85	186.425	24.0653	11830000	0.6068
12/01/87- 4	3.5264	261.09	48.17	118.458	19.1520	9457000	0.6059
12/01/87- 5	3.5265	261.26	48.14	55.907	13.1102	6470000	0.6059

Table 55. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.74 Beta Ratio, 2.8 μm Roughness

Pipe Diameter = 15.563 cm Orifice Diameter = 11.5540 cm

Run ID	Temperature (K)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/13/87- 1	297.03	2.561	17.319	154590	0.60837
02/13/87- 2	297.06	2.562	17.320	154702	0.60839
02/13/87- 3	297.08	2.565	17.326	154825	0.60818
02/13/87- 4	297.12	7.225	28.927	258729	0.60505
02/13/87- 5	297.13	7.221	28.946	258952	0.60557
02/13/87- 6	297.15	7.221	28.942	259032	0.60552
02/13/87- 7	297.16	21.042	49.164	440123	0.60254
02/13/87- 8	297.17	21.000	49.143	440027	0.60288
02/13/87- 9	297.17	20.948	49.113	439855	0.60325
02/13/87-10	297.27	20.925	49.033	440131	0.60263
02/13/87-11	297.30	20.992	49.097	440999	0.60245
02/13/87-12	297.33	21.264	49.418	444186	0.60250
02/13/87-13	297.34	69.248	88.824	798549	0.60009
02/13/87-14	297.34	69.211	88.844	798729	0.60039
02/13/87-15	297.37	69.200	88.836	799195	0.60039
02/13/87-16	297.63	188.792	146.450	1325465	0.59924
02/13/87-17	297.68	188.517	146.337	1325917	0.59922
02/13/87-18	297.73	188.562	146.362	1327621	0.59925
02/17/87-20	296.46	2.557	17.290	152287	0.60779
02/17/87-21	296.99	2.499	17.105	152541	0.60833
02/17/87-22	296.55	2.551	17.285	152594	0.60841
02/17/87-23	296.60	20.795	48.937	432500	0.60329
02/17/87-24	297.01	20.796	48.923	436492	0.60311
02/17/87-25	296.61	20.752	48.916	432410	0.60365
02/17/87-26	297.17	20.615	48.703	436095	0.60305
02/17/87-27	296.81	20.608	48.686	432325	0.60291
02/17/87-28	296.84	20.631	48.710	432830	0.60288
02/17/87-29	296.97	191.503	147.456	1314414	0.59903
02/17/87-30	297.03	191.015	147.326	1315029	0.59927
02/17/87-31	297.10	192.080	147.758	1320960	0.59936

Table 56. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.74 Beta Ratio, 2.8 μm Roughness

Pipe Diameter = 15.563 cm Orifice Diameter = 11.5540 cm

Run ID	Pressure (MPa)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/13/87- 1	3.5300	282.98	44.07	2.808	3.7444	1736000	0.5994
11/13/87- 2	3.5286	276.54	45.17	22.420	10.6653	5035000	0.5964
11/13/87- 3	3.5195	271.48	45.99	59.929	17.6085	8435000	0.5960
11/13/87- 4	3.5289	270.15	46.37	60.156	17.7114	8517000	0.5959
11/13/87- 5	3.5292	269.93	46.42	22.094	10.8567	5159000	0.5958
11/13/87- 6	3.5245	272.76	45.83	1.837	3.0781	1469000	0.5977
11/30/87- 1	3.5230	266.48	47.01	114.770	24.6840	12000000	0.5957
11/30/87- 4	3.5279	254.93	49.51	119.271	25.7781	12982000	0.5948

Table 57. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.74 Beta Ratio, 5.1 μm Roughness

Pipe Diameter = 15.433 cm Orifice Diameter = 11.5540 cm

Run ID	Tempereture (K)	Dif Press (kPe)	Flow Rate (kg/s)	Pipe Reynolds No.	C
02/19/87- 1	299.01	2.583	17.511	164937	0.60802
02/19/87- 2	299.04	2.548	17.398	163984	0.60829
02/19/87- 4	299.10	20.904	49.422	466431	0.60329
02/19/87- 5	299.12	20.937	49.485	467236	0.60359
02/19/87- 6	299.20	189.397	147.911	1399302	0.59985
02/19/87- 7	299.26	189.047	147.834	1400401	0.60010
02/20/87-10	299.56	2.533	17.399	165926	0.61017
02/20/87-11	299.59	2.494	17.259	164695	0.60995
02/20/87-14	299.61	20.693	49.192	469639	0.60357
02/20/87-15	299.63	20.696	49.206	469974	0.60370
02/20/87-16	300.22	189.943	148.207	1433990	0.60025
02/20/87-17	300.29	188.852	147.806	1432570	0.60036
02/25/87-32	300.24	2.542	17.376	168233	0.60835
02/25/87-33	300.30	2.549	17.394	168621	0.60809
02/25/87-34	300.37	20.885	49.376	479381	0.60308
02/25/87-35	300.39	20.886	49.380	479632	0.60313
02/25/87-38	300.64	188.916	147.686	1442484	0.59979
02/25/87-39	300.70	188.830	147.670	1444178	0.59987

Table 58. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.74 Beta Ratio, 5.1 μm Roughness

Pipe Diemeter = 15.433 cm Orifice Diemeter = 11.5540 cm

Run ID	Pressure (MPe)	Tempereture (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rete (kg/s)	Pipe Reynolds No.	C
11/16/87- 1	3.5285	280.15	44.53	2.431	3.5358	1666000	0.6006
11/16/87- 2	3.5285	273.87	45.67	20.848	10.4680	5022000	0.5993
11/16/87- 3	3.5273	268.82	46.61	58.953	17.7808	8656000	0.5983
11/16/87- 4	3.5282	267.04	46.98	58.994	17.8434	8732000	0.5980
11/16/87- 5	3.5277	266.76	47.03	19.875	10.3537	5072000	0.5984
11/16/87- 6	3.5281	270.65	46.28	2.484	3.6269	1756000	0.5982
12/08/87- 1	3.5266	264.98	47.37	109.679	24.4631	12046000	0.5975
12/08/87- 4	3.5273	256.59	49.14	111.547	25.0782	12670000	0.5963
12/08/87- 5	3.5274	255.59	49.37	65.186	19.1947	9727000	0.5970
12/09/87- 1	3.5247	272.54	45.88	107.471	23.8345	11479000	0.5975
12/09/87- 4	3.5290	261.65	48.09	108.852	24.5180	12195000	0.5967
12/09/87- 5	3.5281	260.59	48.30	65.593	19.0082	9485000	0.5957

Table 59. Measured and Calculated Quantities Using Water in the 6-Inch Orifice Meter, 0.74 Beta Ratio, 8.9 μm Roughness

Pipe Diameter = 15.573 cm Orifice Diemeter = 11.5540 cm

Run ID	Tempereture (K)	Dif Press (kPe)	Flow Rete (kg/s)	Pipe Reynolds No.	C
02/26/87- 1	300.28	2.539	17.227	166769	0.60829
02/26/87- 2	300.30	2.526	17.181	166395	0.60832
02/26/87- 5	300.42	20.941	49.163	477369	0.60454
02/26/87- 6	300.41	20.998	49.223	477852	0.60445
02/26/87- 7	300.68	189.602	147.743	1442877	0.60378
02/26/87- 8	300.74	189.131	147.621	1443529	0.60403
02/27/87-11	301.87	2.521	17.140	171776	0.60760
02/27/87-12	301.90	2.529	17.177	172255	0.60789
02/27/87-13	301.91	20.892	49.097	492459	0.60452
02/27/87-14	301.90	20.981	49.200	493396	0.60452
02/27/87-15	301.99	189.021	147.493	1481899	0.60377
02/27/87-16	302.07	189.353	147.659	1486073	0.60393

Table 60. Measured and Calculated Quantities Using Air in the 6-Inch Orifice Meter, 0.74 Beta Ratio, 8.9 μm Roughness

Pipe Diemeter = 15.573 cm Orifice Diemeter = 11.5540 cm

Run ID	Pressure (MPe)	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C
11/16/87- 1	3.5280	278.65	44.79	2.458	3.5462	1663000	0.6022
11/16/87- 2	3.5273	271.32	46.13	20.677	10.4698	5015000	0.6037
11/16/87- 3	3.5272	266.15	47.14	59.012	17.8797	8695000	0.6028
11/16/87- 4	3.5281	264.15	47.56	59.047	17.9582	8785000	0.6027
11/16/87- 5	3.5280	262.87	47.82	20.349	10.5605	5186000	0.6031
11/16/87- 6	3.5280	264.87	47.41	2.403	3.5993	1757000	0.6012
12/08/87- 1	3.5283	264.15	47.56	107.537	24.3597	11917000	0.6045
12/08/87- 4	3.5293	257.09	49.06	108.415	24.8260	12411000	0.6042
12/08/87- 5	3.5284	256.26	49.22	63.259	18.9574	9501000	0.6042

Table 61. Measured and Calculated Quantities Using Nitrogen Gas in the 4-inch Orifice Meter, 0.43 Beta Ratio, 6.9 μm Roughness Honed to 1.3 μm Roughness for Two Pipe Diameters

Pipe Diameter = 10.426 cm Orifice Diameter = 4.4445 cm

Run ID	Pressure MPa	Tempereture (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rete (kg/s)	Pipe Reynolds No.	C	CY_2
43102688- 1	3.9882	288.66	46.90	12.817	1.0441	702100	0.6033	0.6037
43102688- 2	3.9717	288.54	46.72	12.723	1.0370	697700	0.6025	0.6029
43102688- 3	3.8029	287.82	44.85	46.865	1.9486	1315800	0.6009	0.6025
43102688- 4	3.8045	287.34	44.95	47.776	1.9679	1330400	0.6003	0.6019

Table 62. Measured and Calculated Quantities Using Nitrogen Gas in the 4-inch Orifice Meter, 0.55 Beta Ratio, 6.9 μm Roughness Honed to 1.3 μm Roughness for Two Pipe Diameters

Pipe Diameter = 10.426 cm Orifice Diameter = 5.7137 cm

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPe)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
44102688- 1	4.0567	289.06	47.63	2.744	0.8318	558300	0.6053	0.6054
44102688- 2	4.0577	289.21	47.62	2.750	0.8319	558200	0.6048	0.6048
44102688- 3	3.9654	288.52	46.65	7.650	1.3737	924300	0.6048	0.6050
44102688- 4	3.9528	288.39	46.53	7.573	1.3630	917500	0.6039	0.6041
44102688- 1	3.7686	287.36	44.53	21.415	2.2357	1512000	0.6017	0.6024
44102688- 2	3.7619	287.41	44.44	21.199	2.2241	1504200	0.6022	0.6029
44102688- 3	3.8675	287.60	45.66	15.422	1.9205	1296500	0.6017	0.6021
44102688- 4	3.8686	287.70	45.65	15.440	1.9243	1298800	0.6025	0.6030

Table 63. Measured and Calculated Quantities Using Nitrogen Gas in the 4-inch Orifice Meter, 0.67 Beta Ratio, 6.9 μm Roughness Honed to 1.3 μm Roughness for Two Pipe Diameters

Pipe Diameter = 10.426 cm Orifice Diameter = 6.9840 cm

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45101888- 1	3.9693	288.31	46.74	2.660	1.3016	876100	0.6090	0.6091
45101888- 2	3.9640	288.29	46.68	2.636	1.2960	872500	0.6095	0.6096
45101888- 3	3.9002	287.83	46.00	4.713	1.7187	1159200	0.6089	0.6090
45101888- 4	3.8999	287.84	46.00	4.699	1.7123	1154900	0.6075	0.6077
45101888- 5	3.7452	287.12	44.29	8.452	2.2491	1522400	0.6063	0.6065
45101888- 6	3.7356	287.48	44.11	8.435	2.2374	1513300	0.6049	0.6051
45101888- 7	3.8262	287.29	45.22	6.615	2.0089	1357900	0.6058	0.6060
45101888- 8	3.8159	287.59	45.05	6.600	2.0003	1351300	0.6051	0.6052
45101988- 1	3.9712	287.79	46.85	4.688	1.7239	1161800	0.6068	0.6069
45101988- 2	3.9501	287.92	46.58	4.686	1.7159	1156400	0.6058	0.6060
45101988- 3	3.7869	287.66	44.69	8.381	2.2471	1518300	0.6055	0.6058
45101988- 4	3.7814	287.23	44.70	8.340	2.2405	1515500	0.6052	0.6054
45101988- 5	3.8925	287.63	45.95	6.400	1.9911	1343700	0.6056	0.6058
45101988- 6	3.8799	287.61	45.80	6.366	1.9838	1339100	0.6060	0.6061
45101988- 7	3.9974	288.24	47.08	2.792	1.3356	898900	0.6077	0.6078
45101988- 8	3.9976	288.24	47.08	2.801	1.3369	899800	0.6072	0.6073

Table 64. Measured and Calculated Quantities Using Nitrogen Gas in the 4-inch Orifice Meter, 0.73 Beta Ratio, 6.9 μm Roughness Honed to 1.3 μm Roughness for Two Pipe Diameters

Pipe Diameter = 10.368 cm Orifice Diameter = 7.6177 cm

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46101888- 1	3.9625	288.17	46.68	2.486	1.5705	1057600	0.6048	0.6049
46101888- 2	3.9562	288.00	46.64	2.473	1.5661	1055200	0.6051	0.6051
46101888- 3	3.8909	287.80	45.90	3.640	1.8788	1267400	0.6031	0.6032
46101888- 4	3.8860	287.76	45.85	3.624	1.8735	1264100	0.6030	0.6031
46101888- 5	3.7399	286.97	44.25	5.525	2.2666	1534900	0.6013	0.6015
46101888- 6	3.7379	286.94	44.23	5.514	2.2651	1534000	0.6017	0.6018
46101888- 7	3.8203	287.24	45.16	4.397	2.0498	1385800	0.6035	0.6036
46101888- 8	3.8240	287.66	45.13	4.422	2.0545	1387600	0.6034	0.6035
46101988- 1	3.9680	288.40	46.71	2.511	1.5754	1060300	0.6036	0.6037
46101988- 2	3.9712	288.18	46.78	2.508	1.5754	1060800	0.6035	0.6035
46101988- 3	3.7706	287.73	44.49	5.403	2.2507	1520700	0.6022	0.6024
46101988- 4	3.7821	287.15	44.72	5.412	2.2574	1527200	0.6020	0.6021
46101988- 5	3.8520	287.79	45.44	4.536	2.0804	1404100	0.6012	0.6013
46101988- 6	3.8371	287.66	45.29	4.516	2.0786	1403700	0.6030	0.6031
46101988- 7	3.8946	287.85	45.94	3.636	1.8791	1267400	0.6032	0.6033
46101988- 8	3.8971	287.91	45.95	3.630	1.8787	1267000	0.6035	0.6036

Table 65. **Measured and Calculated Quantities Using Nitrogen Gas in the 4-inch Orifice Meter, 0.67 Beta Ratio, 6.9 μm Roughness Honed to 1.3 μm Roughness for Four Pipe Diameters**

Pipe Diameter = 10.426 cm Orifice Diameter = 6.9840 cm

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
45110188- 1	3.8258	287.41	45.20	6.069	1.9212	1298300	0.6050	0.6052
45110188- 2	3.8201	287.42	45.13	6.018	1.9118	1292000	0.6051	0.6053
45110188- 3	3.7012	287.14	43.76	8.711	2.2664	1534800	0.6054	0.6056
45110188- 4	3.7006	286.79	43.81	8.659	2.2593	1531300	0.6049	0.6052
45110188- 5	3.9459	287.95	46.52	2.733	1.3115	883900	0.6067	0.6068
45110188- 6	3.9253	287.97	46.28	2.789	1.3222	891200	0.6072	0.6072
45110188- 7	3.8994	287.95	45.97	4.123	1.6004	1079100	0.6064	0.6065
45110188- 8	3.8845	287.64	45.85	4.100	1.5914	1074000	0.6055	0.6056

Table 66. **Measured and Calculated Quantities Using Nitrogen Gas in the 4-inch Orifice Meter, 0.73 Beta Ratio, 6.9 μm Roughness Honed to 1.3 μm Roughness for Four Pipe Diameters**

Pipe Diameter = 10.426 cm Orifice Diameter = 7.6177 cm

Run ID	Pressure MPa	Temperature (K)	Density (kg/m^3)	Dif Press (kPa)	Flow Rate (kg/s)	Pipe Reynolds No.	C	CY_2
46110188- 1	3.9051	287.79	46.07	2.547	1.5771	1063800	0.6040	0.6041
46110188- 2	3.9000	287.76	46.01	2.536	1.5749	1062400	0.6049	0.6049
46110188- 3	3.7161	287.28	43.92	5.407	2.2391	1515600	0.6028	0.6029
46110188- 4	3.7072	286.99	43.86	5.359	2.2285	1509600	0.6031	0.6032
46110188- 5	3.8056	287.53	44.94	4.312	2.0221	1366400	0.6027	0.6028
46110188- 6	3.7881	287.36	44.76	4.313	2.0205	1366100	0.6034	0.6035
46110188- 7	3.8440	287.43	45.41	3.531	1.8375	1241400	0.6020	0.6021
46110188- 8	3.8380	287.61	45.31	3.532	1.8371	1240700	0.6026	0.6027

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5. AUTHOR(S)

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Chicago, Illinois 60631

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

Flow measurement with orifice flowmeters is simple in concept and can be accurate, but as has been demonstrated in flow measurement test facilities can also result in large errors if any of the significant parameters are not controlled. Many of these parameters are well known and particular care is taken to ensure that they do not cause measurement errors. Others are more subtle and not so easily detected or controlled. One such parameter is the surface finish of the pipe immediately upstream of the orifice plate. Results of an experimental investigation into the effects of this pipe roughness on the orifice discharge coefficient are presented, along with a review of some of the pertinent literature. Measurement errors of approximately 1 percent can result from using meter tubes that are too rough but still within the specification of the standards.

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

air; experimental; flow measurement; gas; orifice discharge coefficient; orifice meter; roughness; surface finish; water

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