

CE 321 Sample Laboratory Report Packet

This packet contains the following materials to help you prepare your lab reports in CE 321:

- An advice table with Dr. Wallace's hints regarding common strengths and weakness of each section of a lab report
- A sample cover memo.
- An annotated sample lab report prepared on a fluids experiment similar to one you might do in this course.

Dr. Roger Wallace's Points-of-View on Successful Lab Reports

Report Component and Specifications	Characteristics of Success	Characteristics of Weakness
Abstract		
<ul style="list-style-type: none"> ❖ Consists of no more than 150-250 words. ❖ States the <i>major</i> objectives. ❖ Briefly describes the methods and materials employed, especially if they are novel or unfamiliar. ❖ Summarizes <i>important</i> results and conclusions. 	<ul style="list-style-type: none"> ✓ Summarizes the entire study within word limits. ✓ Employs concise statements. ✓ Contains specific information. 	<ul style="list-style-type: none"> ▶ Omits critical findings. ▶ Refers reader to figures or tables in the report. ▶ Relies on vague language.
Introduction		
<ul style="list-style-type: none"> ❖ Lists objectives of the study. ❖ Provides background on the experiment, including relevant theory on which the experiment is based. ❖ Refers to important previous studies. 	<ul style="list-style-type: none"> ✓ Usually consists of 1-2 pages. ✓ Provides a rationale for the experiment. ✓ Supplies sufficient background for readers to understand and evaluate this experiment and its results without having to read previous publications. 	<ul style="list-style-type: none"> ▶ Fails to clearly define the problem and the relevance of the experiment.
Methods and Materials		
<ul style="list-style-type: none"> ❖ Provides a sketch of apparatus and its components if readers would not be familiar with it. ❖ Identifies the materials employed and their relevant properties. ❖ Lists in order the procedures performed. 	<ul style="list-style-type: none"> ✓ Identifies by name commonly accepted methods. ✓ Provides only enough detail for a skilled lab technician to replicate the experiment. ✓ Provides more detail if the method is novel or unfamiliar. 	<ul style="list-style-type: none"> ▶ Includes unnecessary detail and makes repeated use of "then." ▶ Fails to use lists or diagrams when those would be helpful.
Results		
<ul style="list-style-type: none"> ❖ Presents all experimental and analytical results. 	<ul style="list-style-type: none"> ✓ Includes reduced data in clear, properly constructed tables and graphs. ✓ States results in clear language and in past tense. ✓ Delays interpretation of results until the Discussion section. 	<ul style="list-style-type: none"> ▶ Fails to summarize overall results. ▶ Fails to present data in formats that reveal critical relationships (trends, cause/effect, etc.) ▶ Fails to identify units of measurement.

Dr. Roger Wallace's Points-of-View on Successful Lab Reports

Report Component and Specifications	Characteristics of Success	Characteristics of Weakness
Discussion		
<ul style="list-style-type: none"> ❖ Interpret the results in light of what you expected based on published information. ❖ Identifies the significant sources of error and assesses the reliability of your results. ❖ Comments on any abnormalities in the procedure that might affect results. ❖ Identifies and explains any unusual or surprising results. 	<ul style="list-style-type: none"> ✓ Compares your results with published results, focusing on the same relationships. ✓ Summarizes the degree to which the experiment achieved its goals. 	<ul style="list-style-type: none"> ▶ The conclusions exaggerate what the results would support. ▶ Fails to give a precise engineering explanation for any failure to obtain results. ▶ Fails to explain or interpret the <i>significance</i> of errors.
Conclusions and Recommendations		
<ul style="list-style-type: none"> ❖ Lists the conclusions reached as a result of this experiment. ❖ Restates any limitations, assumptions or violations of assumptions that might qualify the conclusions. 	<ul style="list-style-type: none"> ✓ List conclusions and recommendations in order of importance. ✓ Links conclusions and recommendations to the information in previous sections of this report. ✓ Cautions the reader about limitations and uncertainties. 	<ul style="list-style-type: none"> ▶ Offers a conclusion or recommendation that has no basis in the results of the experiment. ▶ Fails to caution the reader about any limitations to or uncertainties in the conclusions.
Appendices		
<ul style="list-style-type: none"> ❖ Provides detailed information (raw data, calculations, etc) that might interest only a few readers, especially those who must verify the validity of your results. 	<ul style="list-style-type: none"> ✓ The report is logical and readable without having to refer to the appendices. ✓ The report identifies what material appears in appendices. 	<ul style="list-style-type: none"> ▶ Fails to refer to appendices in the text of the report. ▶ Fails to clearly label and identify appendix material.

General Hints

- ❖ Revise, revise.
 - check all table and figures for accuracy and completeness.
 - check all equations and units of measure.
 - make sure conclusions and recommendations appear in order of importance.
 - avoid strings of long sentences.
 - make sure adjectives and adverbs relate closely to what the data actually show.
 - have someone read the report aloud to you.

Memorandum

To: Roger Wallace, Engineering Standards Director
From: Gabe Studenta, Engineer II
Date: 8/15/2003
Re: Calibration of an Orifice Meter

As you requested in your e-mail of 08/07/03, I have attached a copy of my final report on the Calibration of an Orifice Meter Experiment. Note that discharge predictions from the fundamental discharge relationship and the calibration equation produced errors below the $\pm 10\%$ that you had stipulated. Note also that further experiment may resolve some uncertainties regarding the use of Equation 1. That step might be especially valuable if we want to use this procedure with liquids other than water.

Please call me at ext. 347 if you have any further questions.

- *This cover memo goes with the report and helps the reader recognize what the report contains and why he or she is receiving it. It also highlights important findings. Remember that **memos** are written to readers within the organization; **letters** are written to people outside the organization.*
- *Note that the style of a memo is less formal than that of the report. Use of first person address is natural and normal*

Attachment: Lab Report

Calibration of an Orifice Meter

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August 15, 2003

Abstract

An experiment was conducted to explore the use of an orifice meter and manometer for predicting fluid discharge through a pipe. Fifteen sets of measured discharge and manometer readings were obtained. Discharge was measured by volumetric methods. The calibration equation was fit to the observations. Discharge predictions from both the fundamental discharge relationship and the calibration equation were evaluated and compared. Both equations appeared to be suitable for predicting discharge. The calibration equation provided predictions with less than 2% error while the fundamental discharge relationship had errors as high as 8%. While the calibration equation appears to be more accurate, the fundamental discharge relationship has the advantage of being applicable for fluids other than water. The higher errors associated with the fundamental discharge relationship may have been caused by improperly zeroing the manometer. Measured values of the orifice coefficient K were within 10% of published values.

Note the title and identification of the author.

Note how the Abstract begins with a statement of what was done and why. The style of an abstract is formal, with more frequent use of passive voice than you might employ in other sections of the report.

This abstract (146 words) has appropriate length. Method gets little mention because it was such a standard approach. Note also the mention of *specific* results and conclusions.

<p>Note how the Introduction begins with a description of physical conditions that underlie the experiment. Here we also find the objectives of the experiment and an overview of its structure. These objectives provide the pattern for organizing the Results, Discussion, and Conclusions.</p> <p>Note the correctly formatted equation, with terms defined.</p> <p>Here's an example of a useful list format. Note the parallel grammatical structure of list items.</p> <p>Here the author explains the relevance of previous experiments.</p>	<h2 style="text-align: center;">Introduction</h2> <p>Discharge in a pipe can be measured with an orifice meter composed of an orifice plate and a manometer. The orifice causes a pressure loss across the plate that increases as flow increases. The manometer provides a means of measuring the pressure loss and predicting the flow. This application of orifice meters was explored through achieving the following three objectives:</p> <ol style="list-style-type: none"> 1) Verify the applicability of Eqs. 1 and 2, and compare the resulting equations. 2) Measure the dependence of K on Reynolds number in the apparatus and compare it to published results. 3) Determine the uncertainty (using least squares analysis) in the measured values of K, assuming that the uncertainty in K results from uncertainty in both the manometer readings and the information used to determine discharge. <p>According to Potter and Wiggert (1997) the fundamental discharge relationship for an orifice meter is</p> $Q = KA_o(2gR(S-1))^{0.5} \quad (1)$ <p>Here the pipe discharge Q (m³/s) depends on an orifice coefficient K, the orifice area A_o (m²), the gravitational constant g and the pressure-head drop. In Eq. 1 the pressure-head drop is determined by the product R(S-1) where R is the manometer reading in meters and S is the specific gravity of the manometer fluid. The derivation of Eq. 1 depends on three assumptions:</p> <ol style="list-style-type: none"> 1) The Bernoulli Equation applies to this situation. 2) The pressure measured at the side of the pipe downstream of the orifice plate provides an accurate means of determining the pressure at the centerline of the pipe at that cross section. 3) Coefficients can be introduced into the equation to compensate for the following: <ul style="list-style-type: none"> --that the conditions required for application of the Bernoulli Equation are not met; --that the pressure at the downstream pressure tap does not allow accurate determination of fluid pressure on the central streamline at that cross section. <p>Experiments have shown that the coefficient K depends on two dimensionless numbers—the ratio of the orifice and pipe diameters (D_o/D), and the Reynolds number R_e of the flow. For any fixed diameter ratio, K only depends on the Reynolds number of the flow and tends to a constant value at large Reynolds numbers. As the diameter ratio increases, the variation in K with Reynolds number increases. Eq. 1 may be used to predict flow without calibrating the specific meter if the meter is constructed and operated according to established criteria. In this case K must be obtained from published relationships.</p> <p>The calibration equation</p> $Q = C(R(S-1))^m \quad (2)$
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Even though there is room left on this page, we request that you start each section on a new page.

yields the relationship between pressure drop across the orifice plate and flow rate. Here again the pressure drop is determined by the product $R(S-1)$. To determine the constants C and m one must measure discharge and manometer readings.

Determining the coefficients in Eq. 2 by the method of least squares gave the following calibration equation

$$Q = 0.0102R^{0.4609} \quad (3)$$

Evaluating the uncertainty δ_K in measured values of K was accomplished by assuming the primary sources of error were the values of Q and R . With that assumption, uncertainty δ_K could be calculated with the following equation

$$\delta_K = \left[\left(\frac{\partial K}{\partial Q} \delta_Q \right)^2 + \left(\frac{\partial K}{\partial R} \delta_R \right)^2 \right]^{0.5} \quad (4)$$

Here δ_R and δ_Q represent the uncertainty in measured R and Q .

A diagram of the apparatus is often helpful. Always allow at least two spaces between text and tables or figures.

Again, note the parallel structure in the list, particularly important in procedures. If the list were longer, we might need to break it into stages with steps within each stage.

Methods and Materials

The apparatus consisted of a pipe equipped with an orifice meter, a differential mercury manometer, and a discharge control valve. A pump at the upstream end of the apparatus supplied energy to the water in the pipe to make high flow rates possible. A calibrated measuring tank, used to measure water volume, was located at the pipe outlet. A digital stopwatch was used to measure time.

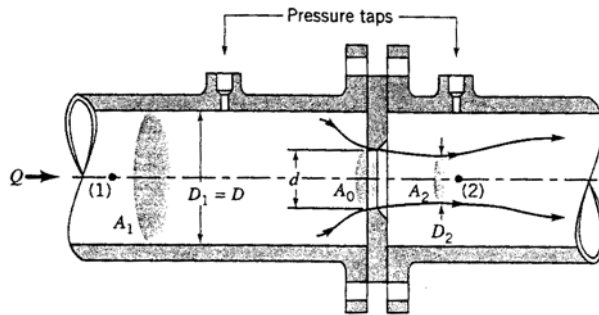


Figure 1. The Orifice Meter Used in This Experiment

The following procedure was used to obtain the basic experimental data:

1. Close all operating valves.
2. Turn on the pump that supplies water to the pipe with the orifice meter.
3. Open the valve on the discharge side of the pump.
4. With no flow in the pipe loop, open the appropriate manometer valves and adjust the manometer reading to show zero pressure drop.
5. Adjust the flow in the pipe by opening the valve at the measuring tank. At this time the flow is diverted directly into the lower reservoir.
6. Divert the water into the measuring tank and measure the time required for a specific volume of water to accumulate.
7. Record the following:
 - water levels at the start of the timed period and at the end of the period,
 - the time interval,
 - and the observed manometer reading.
8. Collect data for 10 to 15 different discharges.

Figures 2 and 3 present comparisons of the basic results of the experiment. Figures show relationships; therefore they may be more useful than tables in the text of the report. Tables, especially long and complex ones, are often found in the Appendix.

The author has suppressed the symbols that represent the equation so they will not be confused with data points (a helpful idea).

Well-designed figures are self-explanatory. Their meaning should be clear. Define all units.

Note that figures are properly labeled *beneath* the chart area.

To the extent possible, place figures in close proximity to the text that refers to them.

Results

The basic data collected, calculations from published values, as well as properties of the system, appear in Tables 2, 3, and 4 in the Appendix (p 10-11.). Z is water surface elevation in the measuring tank, t is time that it took the water surface to rise from Z_1 to Z_2 , and R is the manometer reading in meters of mercury. Q is the measured discharge that was determined from measurements of Z and t ; $Q = A_t(Z_1 - Z_2)/t$. Here A_t is the cross-sectional area of the measurement tank (Table 1), R_e is the Reynolds number of the flow ($R_e = 4Q/(\pi Dv)$), and K was calculated with Eq. 1 using the measured values of Q and R .

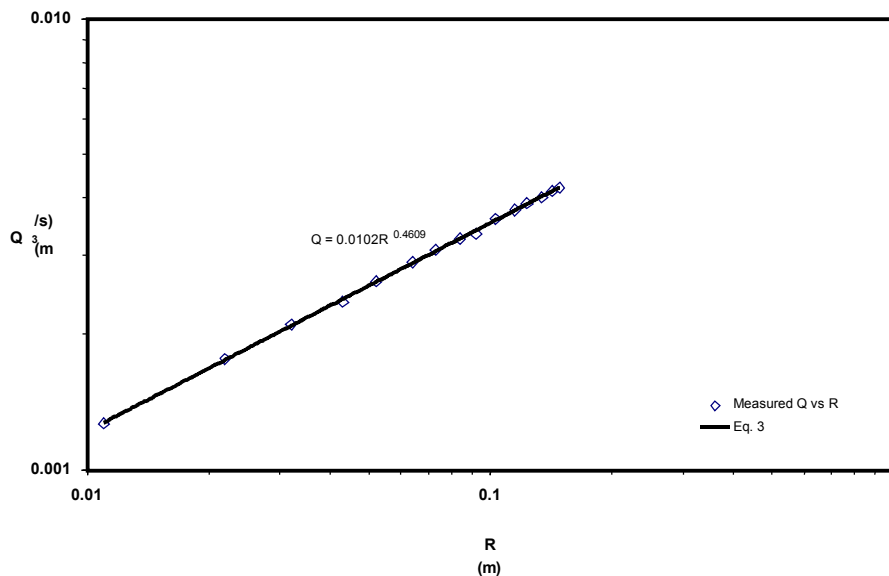


Fig. 2. Comparison of Eq. 3 and Measured Relationship Between Discharge and Manometer Reading

The relationship between measured discharge and manometer reading and the relationship described by Eq. 3 are shown in Figure 2. For practical purposes, these two relationships are identical.

Eq. 1 was also used to establish a relationship between Q and R (Table 2 in Appendix). Here K was found using the published relationship between K and R_e by a trial and error process described by Potter and Wiggert (1997). The relationship obtained with Eq. 1 is compared to the measured relationship in Figure 3. Eq. 1 shows increasing deviation from published values as the manometer reading gets smaller.

These figures, together with the text, tell the “story” of this experiment. Note the careful wording in the figure titles. That helps make the contents clear to readers.

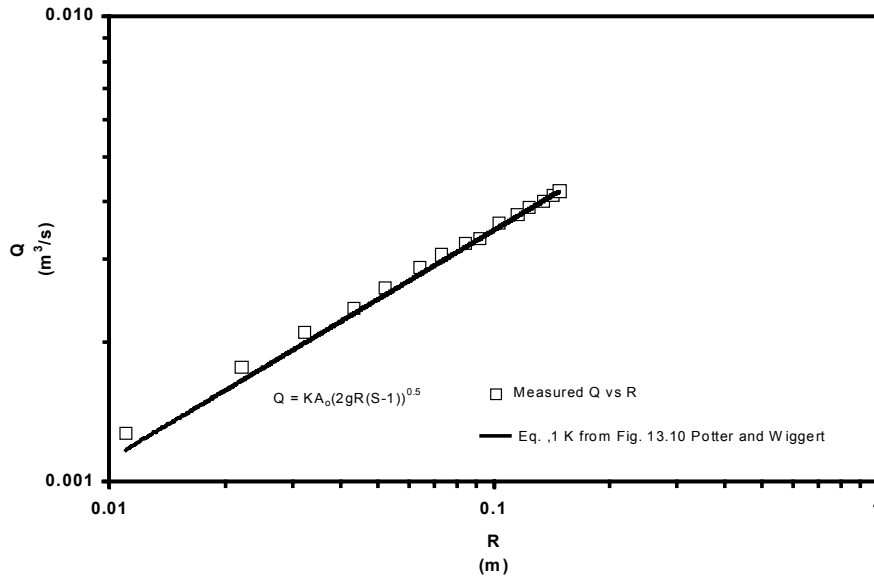


Fig 2. Comparison of Eq. 1 and Measured Relationship Between Discharge and Manometer Reading

Measured values of K (Figure 4) were determined from the experimental data using Eq. 1. Values of K depended on the Reynolds number of the flow. As the Reynolds number increased from 41,100 to 137,000 the value of K decreased from 0.784 to 0.710.

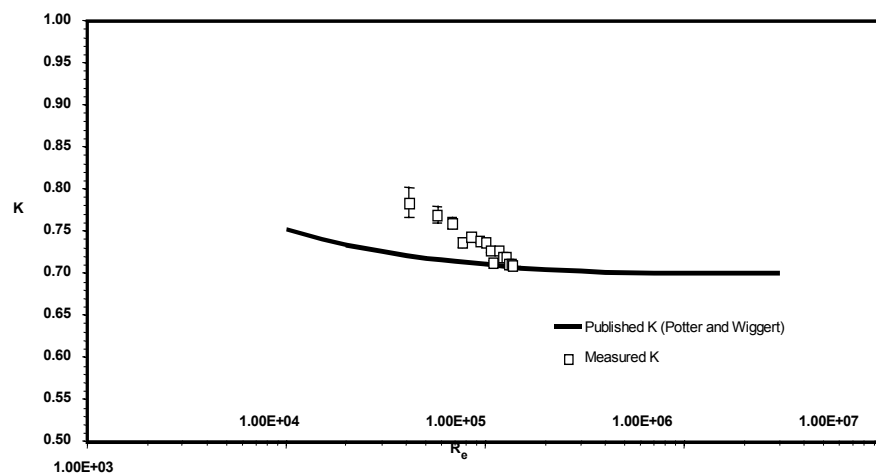


Fig. 4. Values of the Orifice Coefficient K vs Reynolds Number ($D_o/D=0.7$)

Table 1 shows the *comparative data* in detailed format, and so is useful in the text rather than in the Appendix.

Make sure your data are aligned on the decimal points and that values contain the same number of significant figures. *How many* significant figures depends on what is reasonable and useful for the purposes of your experiment.

Do not confuse *least count* with *least squares*. You should understand both terms

Table 1. Comparison of Measured and Predicted Discharge

Experimental Values		Equation 3		Equation 1		
R	Q	Q	Error	K*	Q	Error
(m)	(m ³ /s)	(m ³ /s)	(%)		(m ³ /s)	(%)
0.011	0.00127	0.00128	0.50	0.724	0.00117	-8.21
0.022	0.00176	0.00176	-0.40	0.718	0.00165	-7.16
0.032	0.00210	0.00209	-0.58	0.716	0.00198	-6.08
0.043	0.00236	0.00239	1.39	0.714	0.00229	-3.10
0.052	0.00262	0.00261	-0.19	0.713	0.00251	-4.12
0.064	0.00289	0.00287	-0.51	0.712	0.00278	-3.75
0.073	0.00308	0.00305	-0.79	0.711	0.00297	-3.65
0.084	0.00326	0.00326	0.00	0.710	0.00318	-2.42
0.092	0.00334	0.00340	1.76	0.710	0.00333	-0.27
0.103	0.00360	0.00358	-0.67	0.710	0.00352	-2.29
0.115	0.00377	0.00376	-0.03	0.710	0.00372	-1.20
0.123	0.00390	0.00388	-0.42	0.710	0.00385	-1.33
0.134	0.00402	0.00404	0.48	0.709	0.00401	-0.23
0.142	0.00414	0.00415	0.12	0.708	0.00412	-0.50
0.148	0.00422	0.00423	0.25	0.708	0.00421	-0.21

* K from *Potter and Wiggert*

Errors δ_Q were assumed to be due to errors in Z. The absolute errors of ± 0.001 m in ΔZ and ± 0.0005 m in R were assumed on the basis of least count analysis.

Note how carefully the author chooses words in throughout this report. You should expect to labor a bit when trying to match language and physical data. Therein lies the precision of a superior report.

Discussion

The errors mentioned in this paragraph are not propagated errors, but rather the difference between what the equations predict and what was measured.

This paragraph typifies the kind of *interpretation* that occurs in the Discussion section and demonstrates the difference between Results and Discussion.

Note how the Discussion section goes beyond just identifying the error, but also discusses the source of errors and assesses the impact on the results of the experiment.

Eqs. 1 and 3 can both be used to predict flow for manometer readings ranging from 0.011 to 0.148 meters of mercury. Eq. 3 predicted the measured discharges with errors less than 2%; Eq. 1 was in error by less than about 8% (Table 1). Eq. 3 should provide predictions with less than 2% error so long as the mercury manometer can be kept zeroed at the same position that was used during the experiments. If the greater error observed with Eq. 1 is the result of an error in zeroing the manometer during the experiment then it may be possible to improve the results that can be obtained with Eq. 1. This possibility may be worth exploring because Eq. 1 has a significant advantage over Eq. 3 in that it permits the meter to be used for fluids other than water at 16 C.

The measured values of K fall within about $\pm 10\%$ of the published values (Fig. 4). This is reasonable agreement. Furthermore, these values show a tendency to decrease with increasing Reynolds number just as the published values show.

Standard error propagation methods showed that measured values of K were subject to an uncertainty that ranged from about 2% at Reynolds numbers of $4.1(10)^4$ to less than 0.5% at Reynolds numbers of $1.4(10)^5$. The calculated uncertainty δ_K (Table 4 in Appendix) was used to construct error bars around each measured value of K (Fig. 4). This analysis suggests that the values of K grow more uncertain as the Reynolds number of the flow decreases. Nonetheless, within the range of the measured values, the uncertainties in R and Q do not appear to explain the observed differences between the measured values of K and published values.

The values of K best agree with reported values at high Reynolds numbers, and they show an increased deviation from reported values as the Reynolds number decreased. This consistent deviation suggests a bias in the results. A likely explanation, although it must be verified by experiment, is that the manometer was not properly zeroed during the experiment. The improved agreement obtained by assuming a small (0.003m) zeroing error is shown in Fig. 5 (in Appendix). To discover the true values of K in the apparatus requires that the experiment be rerun to verify the cause of the observed differences.

<p>Placing Conclusions in lists makes them easier to read and gives them a clear hierarchy. Note how they derive from the Results and Discussion and are organized to reflect the original objectives of the experiment—one bullet point for each objective.</p> <p>This experiment did not require Recommendations. If it had, they would appear last, in order of importance, and again derived from what you learned.</p>	<h3 style="text-align: center;">Conclusions</h3> <p>This experiment yielded the following conclusions:</p> <ul style="list-style-type: none"> • Eqs. 1 and 3 can both be used to predict flow in this system for manometer readings ranging from 0.011 to 0.148 meters of mercury. • Measured values of K fall within $\pm 10\%$ of published values, a result acceptable for all but the most carefully designed and executed experiments. Measured values of K show the best agreement with published values at high Reynolds numbers. That agreement decreases as the Reynolds number decreases, but this effect does not entirely explain the disparities. Eq. 3 will provide more accurate predictions if the mercury manometer can be kept zeroed at or near the same position that was used during the experiments. • If the greater uncertainty in predictions with Eq. 1 is the result of an error in zeroing the manometer during the experiment, then it may be possible to improve the accuracy of predictions with Eq. 1. Further experiments to resolve this issue may be worthwhile because Eq. 1 has a significant advantage over Eq. 3 in that it permits the meter to be used for fluids other than water at 16°C.
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Appendix

Table 2. Experimental Data and System Properties

Run	Z ₁	Z ₂	t	R	Q*	R _e	K
	(m)	(m)	(s)	(m)	(m ³ /s)		
1	0.02	0.25	65.43	0.011	0.00127	4.11E+04	0.784
2	0.07	0.30	47.11	0.022	0.00176	5.71E+04	0.770
3	0.15	0.45	51.61	0.032	0.00210	6.80E+04	0.760
4	0.02	0.25	35.22	0.043	0.00236	7.64E+04	0.737
5	0.02	0.30	38.66	0.052	0.00262	8.47E+04	0.743
6	0.02	0.30	35.02	0.064	0.00289	9.35E+04	0.739
7	0.02	0.30	32.87	0.073	0.00308	9.97E+04	0.737
8	0.03	0.35	35.49	0.084	0.00326	1.05E+05	0.728
9	0.02	0.30	30.31	0.092	0.00334	1.08E+05	0.712
10	0.03	0.35	32.09	0.103	0.00360	1.17E+05	0.727
11	0.02	0.30	26.86	0.115	0.00377	1.22E+05	0.719
12	0.07	0.40	30.57	0.123	0.00390	1.26E+05	0.720
13	0.10	0.45	31.45	0.134	0.00402	1.30E+05	0.711
14	0.05	0.40	30.51	0.142	0.00414	1.34E+05	0.712
15	0.14	0.50	30.83	0.148	0.00422	1.37E+05	0.710
D _o (m) =	0.03541		v (m ² /s)	1.14(10) ⁻⁶			
			=				
A _o (m ²) =	0.0009848		S =	13.55			
A _t (m ²) =	0.3612						
D (m) =	0.0508						
T (C) =	16						
*Q = A _t (Z ₂ -Z ₁)/(100t)							

Appendix

Table 3. Q vs R From Published Values of K

$Q = KA_o(2gR(S-1))^{0.5}$			
R	Q	Re	K*
(m)	(m ³ /sec)		
0.011	0.00117	3.79E+04	0.724
0.022	0.00165	5.31E+04	0.718
0.032	0.00198	6.39E+04	0.716
0.043	0.00229	7.39E+04	0.714
0.052	0.00251	8.11E+04	0.713
0.064	0.00278	8.98E+04	0.712
0.073	0.00297	9.58E+04	0.711
0.084	0.00318	1.03E+05	0.710
0.092	0.00333	1.07E+05	0.710
0.103	0.00352	1.14E+05	0.710
0.115	0.00372	1.20E+05	0.710
0.123	0.00385	1.24E+05	0.710
0.134	0.00401	1.29E+05	0.709
0.142	0.00412	1.33E+05	0.708
0.148	0.00421	1.36E+05	0.708

K* from Fig. 13.10 Potter and Wiggert

Table 4. Error in K

δK	K+ δK	K- δK
0.018	0.802	0.766
0.009	0.779	0.761
0.006	0.767	0.754
0.005	0.742	0.731
0.004	0.747	0.738
0.004	0.743	0.735
0.004	0.741	0.734
0.003	0.731	0.725
0.003	0.716	0.709
0.003	0.730	0.724
0.003	0.722	0.716
0.003	0.723	0.717
0.002	0.714	0.709
0.002	0.714	0.710
0.002	0.712	0.708

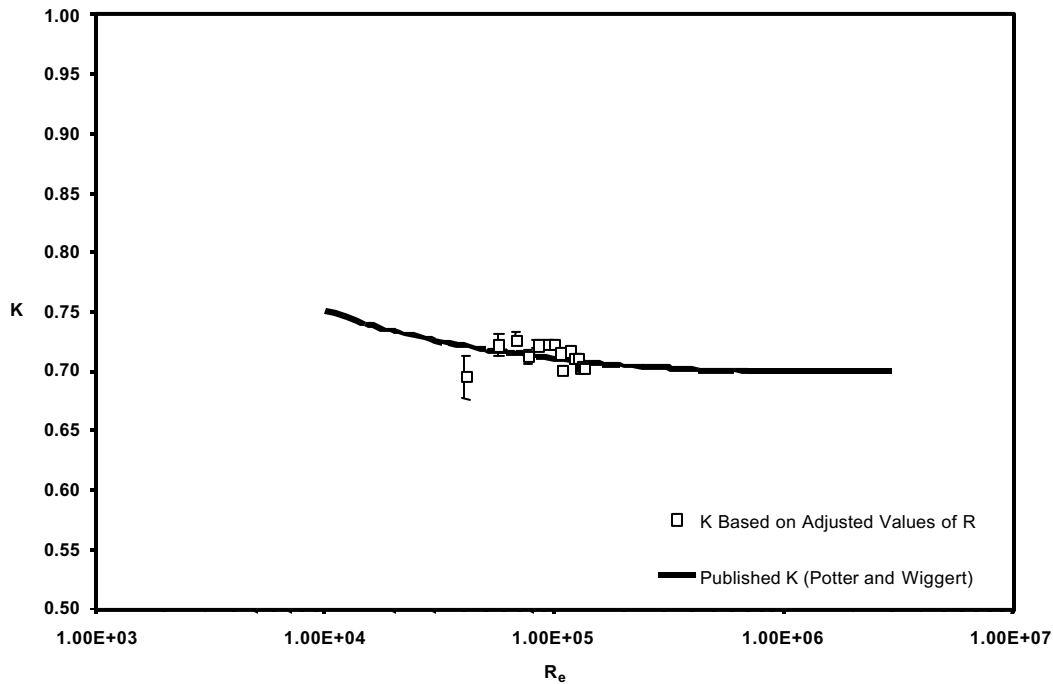


Fig. 5. Values of the Orifice Coefficient vs Reynolds Number (Based on Adjusted Values of R)

References

1. Merle C. Potter and David C, Wiggert. *Mechanics of Fluids, 2nd Ed.* 1997. Prentice-Hall.