Discharge Coefficient Experiment

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Abstract

The coefficient of discharge is an important concept in fluid mechanics. This paper describes a simple and inexpensive experiment to determine the discharge coefficients for nozzles consisting of straight holes and counter-bored holes. The apparatus consists of a straight vertical PVC tube with different nozzles attached at the bottom. The cost of each setup is less than $30 where the cost of the graduated cylinders used to measure the amount of water flowing through the nozzles accounts for half of that cost. If graduated cylinders are already available, the cost per setup is about $15. The tubes are filled with water to generate flow through the nozzles. Varying length tubes are used to vary the head pressure. Only two measurements are required: the volume of water collected and the amount of time it takes to collect the water. It is recommended that at least two students conduct the lab. One continuously fills the tube with water and controls the stopwatch. The second student holds the tube and blocks the nozzle outlet until it is time to start. An fixture could be made to hold the tube and block the outlet so it could be done by a single student if desired. This experiment can be used as a fluid flow demonstration or as a laboratory. There are numerous possible variations of this experiment including multiple combinations of straight and counter-bored holes, contoured holes, different tube lengths and diameters, and different liquids. Example results are reported in the paper where the experiment has been used as a lab. The equations used to develop the theory are provided. Possible sources of error are discussed. Recommendations are also provided.

Introduction

There are many advantages to hands-on experiments which are particularly beneficial for students who are visual and kinesthetic learners. With limited budgets, the challenge is to design suitable lab experiments which are not too costly, particularly when multiple setups are required for larger classes. Penney and Clausen [1] have recently written a very helpful book that provides many relatively inexpensive fluid mechanics and heat transfer experiments. The experiment reported here is an adaptation of a sharp-edged orifice demonstration in the book, which was originally described by Penney et al. [2]. The lab described here is believed to be the least expensive for this type of experiment.

The purpose of the experiment described here is to determine the discharge coefficients for a set of nozzle drillings. An example nozzle, referred to as a fuel gas tip or injector, is shown in Figure 1. These nozzles are used in process burners [3]. The discharge coefficient, C_D, is defined as [4]:

$$C_D = \frac{\text{actual flow rate}}{\text{ideal flow rate}} \tag{1}$$

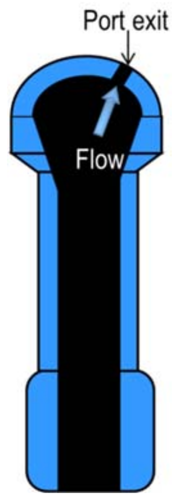

Figure 1. Drawing of a fuel gas delivery nozzle referred to as a tip. The port or hole is drilled straight through the metal with no tapering or chamfering. Most tips typically have multiple holes which vary in diameter, number, and drilling angles.

The closer C_D is to 1, the more efficient the drilling. However, higher C_Ds may be more difficult and expensive to produce. Some example drilling patterns are shown in Figure 2.

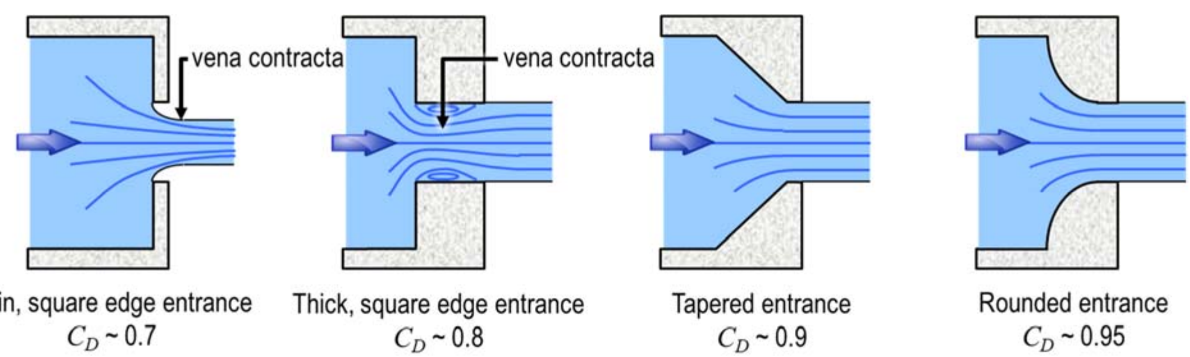

Figure 2. Examples of various port drilling patterns, all with the same exit area (Bussman et al 2013).

The main factors that can affect the discharge coefficient of a nozzle include the following: (1) ratio of port length-to-port diameter, (2) ratio of port diameter to upstream diameter, (3) angle of tapered entrance, and (4) manufacturing tolerances. Figure 3 shows a description of these variables. The nozzle designer must be aware of these variables and consider their effects on equipment performance.

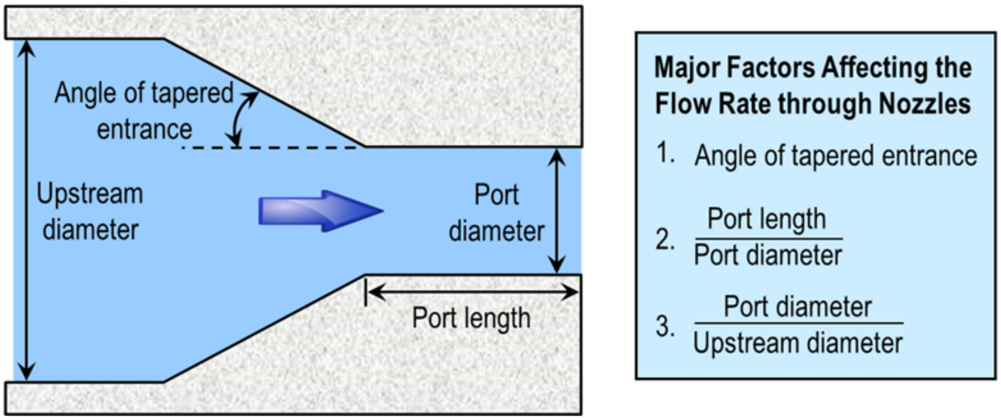

Figure 3. Illustration showing several important factors that influence the flow rate through nozzles [4].

This lab experiment consists of a vertical tube with a cap located at the bottom with a small hole drilled through it (Figure 4). During the experiment, a fluid (typically water) is continuously poured into the vertical pipe and maintained at a constant level.

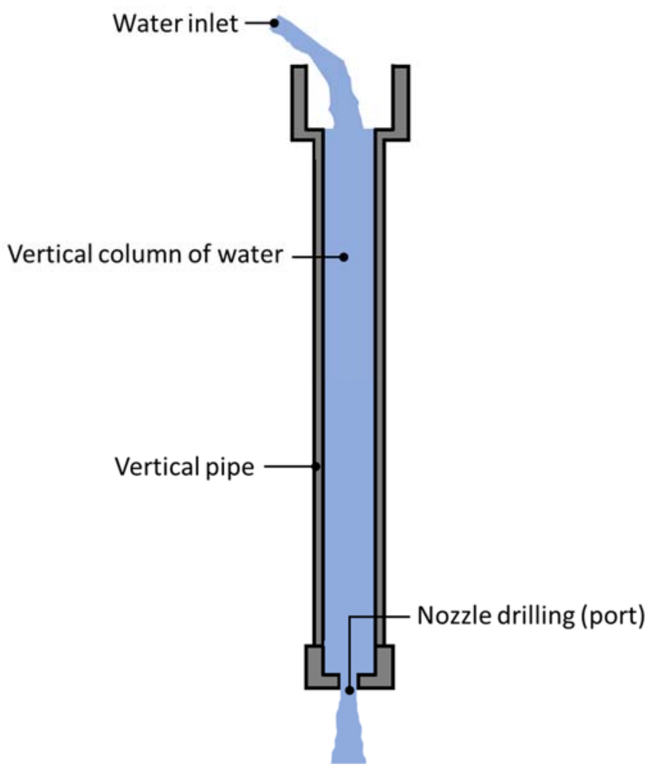

Figure 4. Illustration showing the experimental setup.

Theory

In this section the equations used to calculate the discharge coefficient of the port are derived along with the equation for calculating whether the liquid exiting the port is laminar or turbulent.

The hydrostatic pressure developed by a column of liquid at the nozzle port is calculated as follows:

$$p_h = \rho g h \tag{2}$$

where p_h = hydrostatic pressure (Pa, N/m^2, or kg/m-s^2)

ρ = liquid density (kg/m^3)

g = acceleration of gravity = 9.81 m/s^2

h = height of the liquid column (m)

For this lab, multiple fluid heights are tested. The liquid flow rate through an orifice can be calculated as follows:

$$q_{\text{actual}} = C_D A_2 \sqrt{\frac{2g_c}{\rho}(p_1 - p_2)} \tag{3}$$

where q_{actual} = actual liquid flow rate (m^3/s)

A_2 = area of the port (m^3)

g_c = conversion factor = 1.0 kg-m/N-s^2

p_1 = pressure just upstream of the port (kg/m-s^2)

p_2 = pressure downstream of the port (kg/m-s^2)

For this lab, $p_1 = p_h$ and p_2 = atmospheric pressure = 0. Then for this lab, Equation (2) can be simplified to:

$$q_{\text{actual}} = C_D A_2 \sqrt{\frac{2g_c}{\rho} p_h} \tag{4}$$

In this lab, the variable determined from measurements is the port discharge coefficient, C_D. Solving Equation (4) for the discharge coefficient yields the following equation:

$$C_D = \frac{q_{\text{actual}}}{A_2} \sqrt{\frac{\rho}{2g_c p_h}} \tag{5}$$

Substituting Equation (2) into Equation (5) gives:

$$C_D = \frac{q_{\text{actual}}}{A_2} \sqrt{\frac{\rho}{2g_c(\rho g h)}} = \frac{q_{\text{actual}}}{A_2} \sqrt{\frac{1}{2g_c(gh)}} \tag{6}$$

The actual flow rate of liquid, q_{actual}, is determined experimentally by collecting the liquid exiting the port into a graduated cylinder/beaker over a measured amount of time. Knowing the amount of liquid collect over a given amount of time, the actual flow rate can be calculated as follows:

$$q_{\text{actual}} = \frac{Q_{\text{actual}}}{t} \tag{7}$$

where Q_{actual} = measured liquid volume collected over a given amount of time (m^3)

t = liquid collection time (s)

Substituting Equation (7) into Equation (6) yields the following:

$$C_D = \frac{Q_{\text{actual}}}{tA_2}\sqrt{\frac{1}{2g_c(gh)}} \tag{8}$$

The area of the port, A_2, can be calculated knowing the diameter of the port d_2 as follows:

$$A_2 = \frac{\pi}{4}{d_2}^2 \tag{9}$$

Substituting Equation (9) into Equation (8) yields the final equation for the discharge coefficient of the port:

$$C_D = \frac{4Q_{\text{actual}}}{t\pi {d_2}^2}\sqrt{\frac{1}{2g_c(gh)}} \tag{10}$$

To determine if the flow through the port is laminar or turbulent, one must calculate a non-dimensional parameter called the Reynolds number. The Reynolds number for flow through a port can be calculated as follows:

$$\text{Re}_2 = \frac{\rho v_2 D_2}{\mu} \tag{11}$$

where

ρ = liquid density (kg/m^3)

v_2 = average liquid velocity exiting the port

D_2 = inside port diameter (m)

μ = liquid dynamic viscosity (kg/m-s)

The average liquid velocity exiting the port can be calculated as follows:

$$v_2 = \frac{Q_{\text{actual}}}{tA_2} \tag{12}$$

If Re < 2300, the flow of the liquid through the port is *laminar*. That is, the flow of the liquid will be smooth and orderly. However, if Re > 10,000 the flow is *turbulent*. That is, the liquid exiting the port will consist of randomly swirling, disordered eddies. If Re is between 2300 and 10,000, the flow is in the *transitional* regime where the flow is somewhere between laminar and turbulent.

Experimental Apparatus

This lab assumes there will be four teams of students. It consists of the following components:

- Vertical tubes of varying lengths (see Table 1) to produce different hydrostatic heads and therefore different liquid velocities through the orifice.

  Table 1. Tube lengths and graduated cylinder capacity to collect water flowing through the nozzle.

Tube #	Tube Type	Tube ID (in.)	Nominal Tube Length (ft)	Actual Tube Length (in.)	Graduated Cylinder Capacity (ml)
1	1″ PVC	1.029	1	13.75	500
2	1″ PVC	1.029	2	25.75	1000
3	1″ PVC	1.029	3	37.75	2000
4	1″ PVC	1.029	4	49.75	2000

  There were several reasons for the selection of the above tube lengths. The first is that the discharge coefficient should be independent of the tube length so one of the purposes of the lab is to demonstrate that. The second is the tubes should not be so long that some type of fixture would be needed to hold them. The third is that a standard 10′ section of PVC pipe can be exactly divided into the four selected lengths (1′, 2′, 3′, and 4′).

- Old soda bottles – the bottles are used to pour water into the top of the tube to maintain a given liquid height. These are an inexpensive means for keeping the tubes filled with liquid to maintain a constant head pressure.

- Removable PVC caps – Figure 5 shows a photo of the PVC caps used. Each cap is designed with a different drilling pattern as shown in Table 2. Figure 6 shows a close-up of the drilling for Cap A. Figure 7 shows a drawing of the configuration for Cap D where the hole is counter-bored.

Table 2. Cap configurations.

Cap #	Cap Description
A	5/64″ straight hole
B	3/32″ straight hole
C	1/8″ straight hole
D	5/64″ hole w/1/8″ chamfer

Figure 5. Caps used for experiments made of 1″ PVC.

Figure 6. View of Cap A from the outside.

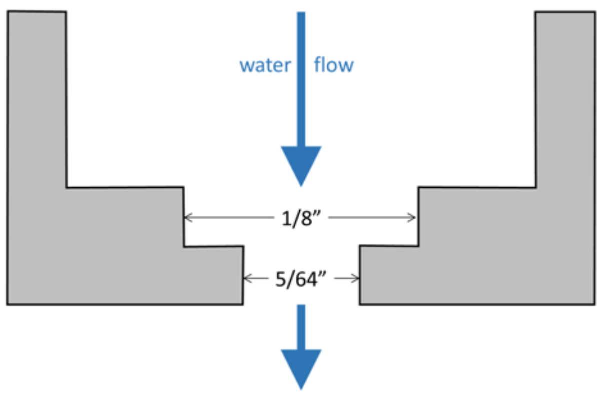

Figure 7. Cap D configuration.

- Graduated cylinders/beakers – the purpose of the cylinders is to collect the liquid that flows through a cap over a given amount of time. The size of the cylinder for each tube is shown in Table 1. These were selected to be reasonably priced and to give approximately 30 – 60 s of collection time.

- Stop watch – this is used to measure the time the liquid flows into the graduated cylinder (students typically use their cell phones).

- Buckets/pans –used to collect any liquid not caught in the graduated cylinder/beaker.

The cost of each tube set is less than $10. The caps are approximately $1.50 each. The graduated cylinders used here were all less than $15 each. If not readily available, cleaner and glue for assembling the PVC components is less than $20.

The fabrication of the apparatus is very simple. The PVC tube is cut to the appropriate length. A PVC adapter, which has a female slip connection on one side which is the same size as the tube and a threaded male connector on the other side (to thread the cap onto), is glued onto one end of the tube. Another PVC fitting, which has a female slip connection on one side the same size as the tube and a female slip connection on the other size larger than the tube (see Figure 8), is glued onto the other end of the tube. The final tube assembly for the shortest tube is shown in Figure 9.

Figure 8. PVC adapter (1″ tube x 2″ tube) used on the fill end of the tube.

Figure 9. Assembly for 1′ nominal tube length.

Procedure

1. Attach the appropriate cap (A, B, C, or D) to the proper tube (1, 2, 3, or 4).
2. One person should hold the tube vertically and place a finger over the hole in the cap to prevent water from flowing through it (see Figure 10).
3. Fill the tube with water to the top of the shelf of the 1″ tube (not all the way to the top of the 2″ opening).
4. Center the graduated cylinder in the bucket and center the tube over the graduated cylinder with the cap pointing down toward the graduated cylinder.
5. Fill the soda bottle with water.
6. When ready to begin, simultaneously remove the finger over the hole in the cap so water begins to flow through the orifice and start the stopwatch.
7. Continuously add water from the soda bottle to the top of the tube to keep the water level height at the top of the tube as shown in Figure 11.
8. Simultaneously put a finger over the orifice to stop the flow and stop the stopwatch when the graduated cylinder is nearly full. Make sure not to fill the graduated cylinder higher than the highest graduation mark. Record the volume of water drained from the tube (see Figure 12) and the time to fill the graduated cylinder.
9. If you will be repeating a test with the same cap, keep a finger over the hole in the cap to keep water in the tube which saves time refilling the tube for the next run.
10. If the caps will be changed, stop adding water to the tube and let the water remaining in the tube drain into the bucket. The process can be expedited by removing the cap or turning the tube upside down and letting the water drain out the open end.
11. Record the amount of liquid collected in the graduated cylinder and the amount of time the liquid was collected.
12. Repeat steps 1-11 as many times as required.

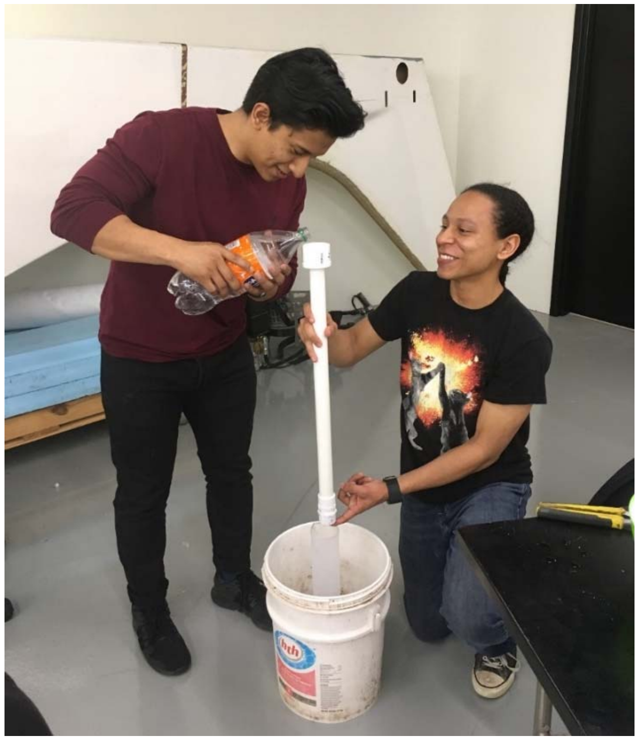

Figure 10 Student on right holding tube with right hand and with finger over opening with the left hand. Student on the left maintaining water level with old soda bottle filled with water. A graduated cylinder is inside the bucket.

Figure 11 Student continuously filling the 1′ tube.

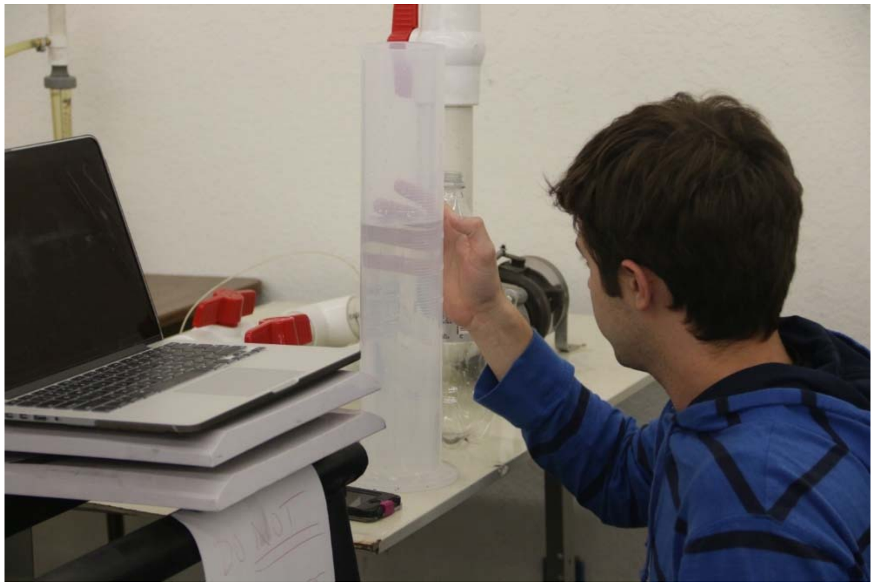

Figure 12 Determining volume of water drained from the tube.

Calculations

These calculations should be done for each repeated run:

1. Hydrostatic pressure for each tube length, p_h
2. Actual measured water flow rate, q_{actual}
3. Coefficient of discharge, C_D
4. Average velocity through the orifice, v_2
5. Reynolds Number through the orifice, Re_2
6. Determine if the flow is laminar, transitional, or turbulent

Calculate the average and standard deviation for each set of runs.

Example Results

This experiment was conducted in the spring semesters of 2018 and 2019. There were four teams of five or six students on each team. In the spring 2018 semester the lab sessions were only 50 minutes in length, so each team was assigned to a single tube length and all four caps. Students were required to run each tube/cap combination at least three times. They were then to share their raw data with the rest of the class so all groups would have data for all four tube lengths. Figure 13 shows the calculated results for the coefficients of discharge for the four nozzle configurations. The raw data and calculations are given in the Appendix in Table 4.

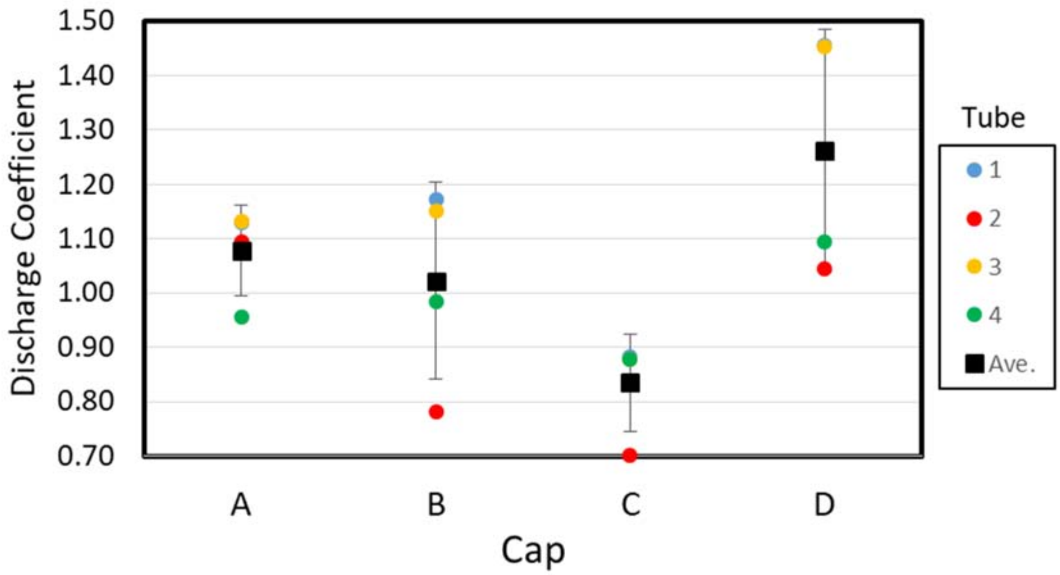

Figure 13 Example coefficient of discharge results before any modifications.

As can be seen, many of the results were not physically possible with discharge coefficients greater than 1. The hole drillings were checked and most of them were larger than the nominal drill sizes given in Table 2. This is likely due to using a makeshift drill press to make the holes. When the corrected hole diameters were used in the calculations, the results are shown in Figure 14. The corrected data and calculations are shown in Table 5 in the Appendix.

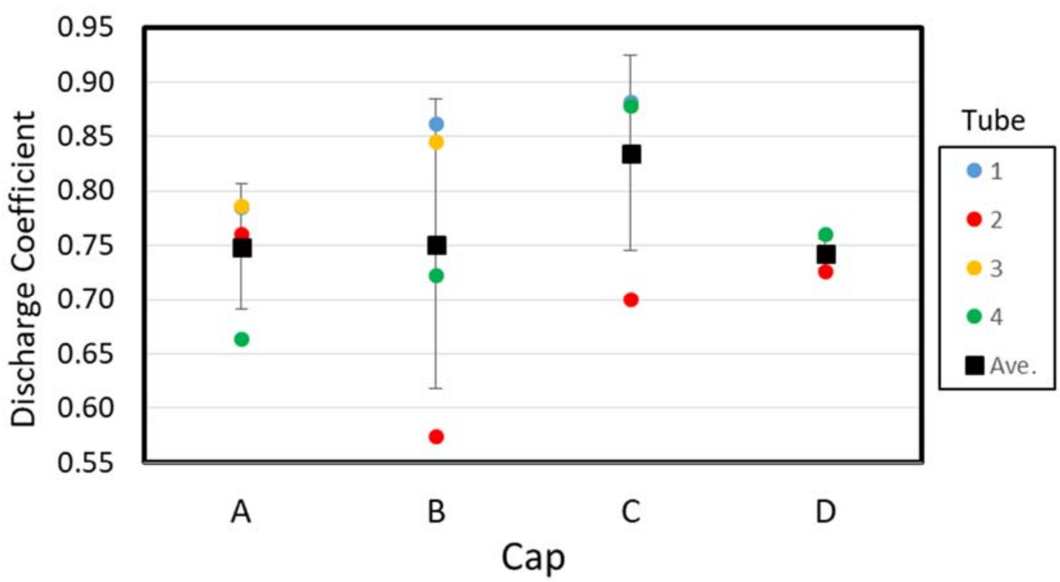

Figure 14 Example coefficient of discharge results after using the corrected hole diameters.

For this lab, there were a total of 9 different runs conducted and 21 students in both semesters divided into 4 teams. The discharge coefficient lab described here had the second lowest average grade of the 9 labs conducted during the course at 81.8% with a range of 77.0 to 88.0% and a median of 81.0%. The main problem was described above where discharge coefficients greater than 1.0 were calculated. None of the teams provided explanations for this discrepancy of discharge coefficients greater than 1.0. Future lab manuals will include a reminder to discuss possible causes for calculating discharge coefficients greater than 1.0.

A survey was given to the spring 2019 class after they completed the lab and again after they turned in the lab report a week later. The first question on each survey was how this lab compared to the other 8 labs completed in the course. If "Much worse" is worth 1 point and "Much better" is worth 5 points, the students rated this lab as a 4.0 (equivalent to "A little better") after completing the lab and as a 3.6 (between "About the same" and "A little better") after completing the lab report. The distribution of responses is shown in Figure 15.

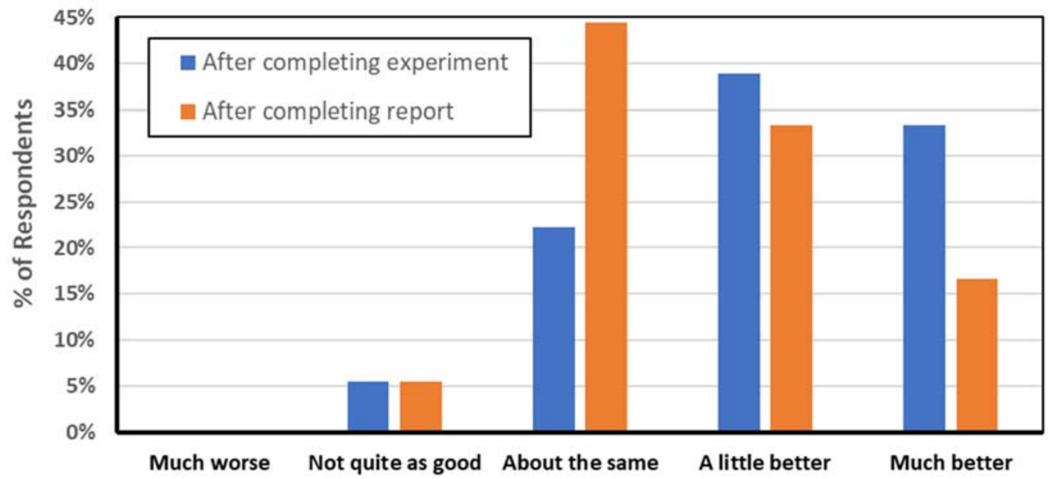

Figure 15 Responses to how this lab compared to the other labs in the course in surveys given after completing the experiment and again after completing the lab report.

The second question on the survey was "What did you learn from this lab?" Most students said something related to discharge coefficient and variables that impact it. The third question was "What did you like most about this lab?" Common responses were that the lab was fun, interactive, and involved the entire team. The fourth question was "What did you like least about this lab?" Common responses were the lack of funnels to help put the water back in the empty soda bottles, not having wrenches to remove the caps that were tightened to stop water from leaking out the cap threads, and the long length of time it took for the groups with the longer tubes. The fifth question was "What suggestions do you have to improve this lab?" Some common responses included having funnels, wrenches, and something to hold the tubes.

Recommendations

There are many possible variations of this experiment which can be used as a laboratory or as a demonstration. More combinations of straight hole sizes and counter-bored holes could be used. If more time is available, each group could test multiple tube lengths and conduct more repeat runs. Other fluids could be used as well.

There are a few parameters where there is a significant potential for error. Only two measurements are made during the experiment: the drainage time and the amount of water collected. In both cases, the larger these values the lower the relative error. For example, if the drainage time is 30 s with a 1 s uncertainty, this equates to an uncertainty of 3.3%. However, if the drainage time is 5 min with an uncertainty of 1 s, that would only be an uncertainty of 0.33%. For both the drainage time and the volume of water collected, the larger the graduated cylinder and collection time the lower the relative error.

Another parameter that can produce a significant error is the size of the hole in the nozzle as demonstrated in the example above. If a precise hole cannot be properly drilled, then another option is to precisely measure the hole diameter. This could be done with a micrometer, using an extensive set of drill bits to find the one that most closely fits into the hole, or to use a set of go/no-go gauges. In general, the measurement error will be relatively less the larger the hole. This also generally means a larger graduated cylinder would be needed since the water will drain out faster through a larger hole. Something larger than a soda bottle or multiple soda bottles may also be needed to fill the tubes. Another potential source of error is the water level height which depends on the ability of the student filling to tube to maintain the desired height. The longer the tube, the lower the relative error in the water height. In general, the purpose of the experiment is not necessarily high accuracy but to demonstrate principles and to properly estimate the potential error.

Based on student feedback, funnels, wrenches, and paper towels should be included. Another suggestion is to give each team a single cap/hole combination and rotate the teams between the tubes. Teams would rotate to another tube after all teams have finished their tests on their given tube. This would make the time to complete the lab essentially the same for each group rather than the current design where teams are assigned a tube and rotate caps so the teams with the shorter tubes finish more quickly than those with the long tubes.

References

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Appendix

Table 3. Data table for 4 teams, 4 tubes, and 4 cap configurations.

Team	Pipe #	Cap #	Run #	Water Collected (ml)	Time (s)
1	1	A	1		
			2		
			3		
		B	4		
			5		
			6		
		C	7		
			8		
			9		
		D	10		
			11		
			12		
2	2	A	13		
			14		
			15		
		B	16		
			17		
			18		
		C	19		
			20		
			21		
		D	22		
			23		
			24		
3	3	A	25		
			26		
			27		
		B	28		
			29		
			30		
		C	31		
			32		
			33		
		D	34		
			35		
			36		
4	4	A	37		
			38		
			39		
		B	40		
			41		
			42		
		C	43		
			44		
			45		
		D	46		
			47		
			48		

Table 4. Data and calculations before corrections for spring 2018 class.

Tube	Cap	Run	D1 (in.)	A1 (m2)	D2 (in.)	A2 (m2)	Pipe Length (in.)	ph (kg/m-s2)	Q (ml)	t (s)	qactual (m3/s)	CD	CD (ave.)	SD
1	A	1	1.029	0.00054	0.078125	3.0927E-06	13.75	3426	500	55.1	9.07E-06	1.12		
		2	1.029	0.00054	0.078125	3.0927E-06	13.75	3426	500	54.5	9.17E-06	1.13		
		3	1.029	0.00054	0.078125	3.0927E-06	13.75	3426	500	54.4	9.19E-06	1.14	1.13	0.0078
	B	1	1.029	0.00054	0.09375	4.4535E-06	13.75	3426	500	37.1	1.35E-05	1.16		
		2	1.029	0.00054	0.09375	4.4535E-06	13.75	3426	500	36.1	1.39E-05	1.19		
		3	1.029	0.00054	0.09375	4.4535E-06	13.75	3426	500	36.5	1.37E-05	1.18	1.17	0.0161
	C	1	1.029	0.00054	0.125	7.9173E-06	13.75	3426	500	27.7	1.81E-05	0.87		
		2	1.029	0.00054	0.125	7.9173E-06	13.75	3426	500	26.9	1.86E-05	0.90		
		3	1.029	0.00054	0.125	7.9173E-06	13.75	3426	500	27.5	1.82E-05	0.88	0.88	0.0135
	D	1	1.029	0.00054	0.078125	3.0927E-06	13.75	3426	500	42.3	1.18E-05	1.46		
		2	1.029	0.00054	0.078125	3.0927E-06	13.75	3426	500	42.6	1.17E-05	1.45		
		3	1.029	0.00054	0.078125	3.0927E-06	13.75	3426	500	42.4	1.18E-05	1.46	1.46	0.0052
2	A	1	1.029	0.00054	0.078125	3.0927E-06	25.75	6416	985	81	1.22E-05	1.10		
		2	1.029	0.00054	0.078125	3.0927E-06	25.75	6416	998	82	1.22E-05	1.10		
		3	1.029	0.00054	0.078125	3.0927E-06	25.75	6416	1000	83	1.20E-05	1.09	1.09	0.0061
	B	1	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	980	79	1.24E-05	0.78		
		2	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	998	77	1.30E-05	0.81		
		3	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	1000	83	1.20E-05	0.76	0.78	0.0288
	C	1	1.029	0.00054	0.125	7.9173E-06	25.75	6416	1000	50	2.00E-05	0.71		
		2	1.029	0.00054	0.125	7.9173E-06	25.75	6416	960	49	1.96E-05	0.69		
		3	1.029	0.00054	0.125	7.9173E-06	25.75	6416	980	49	2.00E-05	0.71	0.70	0.0083
	D	1	1.029	0.00054	0.078125	3.0927E-06	25.75	6416	985	84	1.17E-05	1.06		
		2	1.029	0.00054	0.078125	3.0927E-06	25.75	6416	1000	87	1.15E-05	1.04		
		3	1.029	0.00054	0.078125	3.0927E-06	25.75	6416	990	86	1.15E-05	1.04	1.05	0.0117
3	A	1	1.029	0.00054	0.078125	3.0927E-06	37.75	9406	2000	130	1.54E-05	1.15		
		2	1.029	0.00054	0.078125	3.0927E-06	37.75	9406	2000	132	1.52E-05	1.13		
		3	1.029	0.00054	0.078125	3.0927E-06	37.75	9406	2000	133	1.50E-05	1.12	1.13	0.0132
	B	1	1.029	0.00054	0.09375	4.4535E-06	37.75	9406	2000	89	2.25E-05	1.16		
		2	1.029	0.00054	0.09375	4.4535E-06	37.75	9406	2000	91	2.20E-05	1.14		
		3	1.029	0.00054	0.09375	4.4535E-06	37.75	9406	2000	90	2.22E-05	1.15	1.15	0.0128
	C	1	1.029	0.00054	0.125	7.9173E-06	37.75	9406	2000	67	2.99E-05	0.87		
		2	1.029	0.00054	0.125	7.9173E-06	37.75	9406	2000	66	3.03E-05	0.88		
		3	1.029	0.00054	0.125	7.9173E-06	37.75	9406	2000	66	3.03E-05	0.88	0.88	0.0076
	D	1	1.029	0.00054	0.078125	3.0927E-06	37.75	9406	2000	101	1.98E-05	1.48		
		2	1.029	0.00054	0.078125	3.0927E-06	37.75	9406	2000	104	1.92E-05	1.43		
		3	1.029	0.00054	0.078125	3.0927E-06	37.75	9406	2000	103	1.94E-05	1.45	1.45	0.0217
4	A	1	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1510	105	1.44E-05	0.93		
		2	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1310	86	1.52E-05	0.99		
		3	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1200	81	1.48E-05	0.96		
		4	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1400	97	1.44E-05	0.94	0.96	0.0257
	B	1	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1380	63	2.19E-05	0.99		
		2	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1340	61	2.20E-05	0.99		
		3	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1340	62	2.16E-05	0.97		
		4	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1280	59	2.17E-05	0.98	0.98	0.0076
	C	1	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1430	47	3.04E-05	0.77		
		2	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1340	43	3.12E-05	0.79		
		3	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1400	46	3.04E-05	0.77		
		4	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1220	41	2.98E-05	0.75	0.77	0.0146
	D	1	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1420	84	1.69E-05	1.10		
		2	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1360	81	1.68E-05	1.09		
		3	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1320	78	1.69E-05	1.10		
		4	1.029	0.00054	0.078125	3.0927E-06	49.75	12396	1360	81	1.68E-05	1.09	1.09	0.0047

Table 5. Data and calculations after corrections for spring 2018 class.

Tube	Cap	Run	D1 (in.)	A1 (m2)	D2 (in.)	A2 (m2)	Pipe Length (in.)	ph (kg/m-s2)	Q (ml)	t (s)	qactual (m3/s)	CD	CD (ave.)	SD
1	A	1	1.029	0.00054	0.09375	4.4535E-06	13.75	3426	500	55.1	9.07E-06	0.78		
		2	1.029	0.00054	0.09375	4.4535E-06	13.75	3426	500	54.5	9.17E-06	0.79		
		3	1.029	0.00054	0.09375	4.4535E-06	13.75	3426	500	54.4	9.19E-06	0.79	0.78	0.0054
	B	1	1.029	0.00054	0.109375	6.0617E-06	13.75	3426	500	37.1	1.35E-05	0.85		
		2	1.029	0.00054	0.109375	6.0617E-06	13.75	3426	500	36.1	1.39E-05	0.87		
		3	1.029	0.00054	0.109375	6.0617E-06	13.75	3426	500	36.5	1.37E-05	0.86	0.86	0.0118
	C	1	1.029	0.00054	0.125	7.9173E-06	13.75	3426	500	27.7	1.81E-05	0.87		
		2	1.029	0.00054	0.125	7.9173E-06	13.75	3426	500	26.9	1.86E-05	0.90		
		3	1.029	0.00054	0.125	7.9173E-06	13.75	3426	500	27.5	1.82E-05	0.88	0.88	0.0135
	D	1	1.029	0.00054	0.109375	6.0617E-06	13.75	3426	500	42.3	1.18E-05	0.74		
		2	1.029	0.00054	0.109375	6.0617E-06	13.75	3426	500	42.6	1.17E-05	0.74		
		3	1.029	0.00054	0.109375	6.0617E-06	13.75	3426	500	42.4	1.18E-05	0.74	0.74	0.0027
2	A	1	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	985	81	1.22E-05	0.76		
		2	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	998	82	1.22E-05	0.76		
		3	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	1000	83	1.20E-05	0.76	0.76	0.0043
	B	1	1.029	0.00054	0.109375	6.0617E-06	25.75	6416	980	79	1.24E-05	0.57		
		2	1.029	0.00054	0.109375	6.0617E-06	25.75	6416	998	77	1.30E-05	0.60		
		3	1.029	0.00054	0.109375	6.0617E-06	25.75	6416	1000	83	1.20E-05	0.55	0.57	0.0212
	C	1	1.029	0.00054	0.125	7.9173E-06	25.75	6416	1000	50	2.00E-05	0.71		
		2	1.029	0.00054	0.125	7.9173E-06	25.75	6416	960	49	1.96E-05	0.69		
		3	1.029	0.00054	0.125	7.9173E-06	25.75	6416	980	49	2.00E-05	0.71	0.70	0.0083
	D	1	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	985	84	1.17E-05	0.74		
		2	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	1000	87	1.15E-05	0.72		
		3	1.029	0.00054	0.09375	4.4535E-06	25.75	6416	990	86	1.15E-05	0.72	0.73	0.0081
3	A	1	1.029	0.00054	0.09375	4.4535E-06	37.75	9406	2000	130	1.54E-05	0.80		
		2	1.029	0.00054	0.09375	4.4535E-06	37.75	9406	2000	132	1.52E-05	0.78		
		3	1.029	0.00054	0.09375	4.4535E-06	37.75	9406	2000	133	1.50E-05	0.78	0.79	0.0092
	B	1	1.029	0.00054	0.109375	6.0617E-06	37.75	9406	2000	89	2.25E-05	0.85		
		2	1.029	0.00054	0.109375	6.0617E-06	37.75	9406	2000	91	2.20E-05	0.84		
		3	1.029	0.00054	0.109375	6.0617E-06	37.75	9406	2000	90	2.22E-05	0.85	0.85	0.0094
	C	1	1.029	0.00054	0.125	7.9173E-06	37.75	9406	2000	67	2.99E-05	0.87		
		2	1.029	0.00054	0.125	7.9173E-06	37.75	9406	2000	66	3.03E-05	0.88		
		3	1.029	0.00054	0.125	7.9173E-06	37.75	9406	2000	66	3.03E-05	0.88	0.88	0.0076
	D	1	1.029	0.00054	0.109375	6.0617E-06	37.75	9406	2000	101	1.98E-05	0.75		
		2	1.029	0.00054	0.109375	6.0617E-06	37.75	9406	2000	104	1.92E-05	0.73		
		3	1.029	0.00054	0.109375	6.0617E-06	37.75	9406	2000	103	1.94E-05	0.74	0.74	0.0111
4	A	1	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1510	105	1.44E-05	0.65		
		2	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1310	86	1.52E-05	0.69		
		3	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1200	81	1.48E-05	0.67		
		4	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1400	97	1.44E-05	0.65	0.66	0.0178
	B	1	1.029	0.00054	0.109375	6.0617E-06	49.75	12396	1380	63	2.19E-05	0.73		
		2	1.029	0.00054	0.109375	6.0617E-06	49.75	12396	1340	61	2.20E-05	0.73		
		3	1.029	0.00054	0.109375	6.0617E-06	49.75	12396	1340	62	2.16E-05	0.72		
		4	1.029	0.00054	0.109375	6.0617E-06	49.75	12396	1280	59	2.17E-05	0.72	0.72	0.0056
	C	1	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1430	47	3.04E-05	0.77		
		2	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1340	43	3.12E-05	0.79		
		3	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1400	46	3.04E-05	0.77		
		4	1.029	0.00054	0.125	7.9173E-06	49.75	12396	1220	41	2.98E-05	0.75	0.77	0.0146
	D	1	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1420	84	1.69E-05	0.76		
		2	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1360	81	1.68E-05	0.76		
		3	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1320	78	1.69E-05	0.76		
		4	1.029	0.00054	0.09375	4.4535E-06	49.75	12396	1360	81	1.68E-05	0.76	0.76	0.0032