International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET)

ISSN 2455-4863 (Online) www.ijisset.org Volume: 5 Issue: 2 | 2019

An Introductory Experimental Study Involving Volumetric Flow Rates

Musaed Alkhurafi, Naser Alrashoud, Esraa Huseen, Justin Le, Jonathan Perez, Mildred Renteria, Youssef Taher, Tadeh Zirakian*, and David Boyajian

Dept. of Civil Engineering and Construction Management, California State University, Northridge, CA, USA

Corresponding Author; ***Tadeh Zirakian***, *Phone: +1-818-677-7718 & E-mail: tadeh.zirakian@csun.edu.*

Abstract: *This paper reports an experimental study, performed by a group of civil engineering undergraduate students, under the supervision of Drs. Tadeh Zirakian and David Boyajian at the California State University, Northridge (CSUN). The experiment consisted of a modified water tank, outfitted with differently shaped pipes [curved and 90° bend] of assorted diameters for the experiment. Assuming there were zero energy losses, the students were responsible for using the experimental apparatus to collect the necessary data and subsequently determine the volumetric flow rate and discharge coefficient values for each associated outlet fitting. The results show that the volumetric flow rate increases as diameter increases, while the discharge coefficient decreases as the pipe diameter increases. This effort is geared at enhancing student educational objectives by requiring teamwork, creativity, design and fabrication, problem solving, and analysis and interpretation of results. Throughout the development of the project design, the concepts just mentioned were put into practice with the purpose of solidifying the comprehensive knowledge obtained throughout the civil engineering capstone course. It is important to mention the most important purpose of this project is to present the collaboration of undergraduate students with diverse backgrounds and cultures; along with the participation and leadership of women in engineering projects. Effort, work, and research are key factors in the development and performance of this project, carried out by undergraduate students to show the final results, so that this experimental research may motivate and inspire many more students in the future, not only inside the classrooms of this university, but throughout the world.*

Keywords: *Undergraduate research, volumetric flow rate, skills, problem solving, teamwork, women in engineering, leadership.*

1. INTRODUCTION

Civil engineering is one of the broadest branches of the engineering. It has subspecialty branches that involve fluid mechanics, which is a main consideration needed to design sewerage systems and pipelines. Students can build their fluid mechanics (Fig. 1) knowledge and enhance them in the laboratory as they perform experiments that involve their topics of study.

In this experiment, a thirty-five gallon, polypropylene storage box (Fig. 2), an electric drill, special drill bits, valves sizes of ½”, ¾”, 1” 1½”, and 2”, and the same-sized assortment of 90-degree elbow fittings and curved pipes were used. Five holes of different sizes were drilled at a spacing of six inches to prevent the tank walls from fracturing. The two types of pipes, 90-degree elbow fittings and curved pipes, were tested with varying diameter sizes to investigate their volumetric flow rates.

Figure 1: *Pipe fabrication*

Figure 2: *35-gallon storage container*

The primary aim of undertaking the experiment is to create an avenue where undergraduate students can take part in problem solving activities. It is indeed a project-based learning centered approach where the instructor merely serves as a facilitator while the students design and conduct the actual experiment [1]. Giving ample time to students to take an active part of in an experiment like this one would help them use the skills that they have acquired into a practical use [1,2,3]. Some of the skills include; teamwork, where the students are required to work collaboratively and jointly obtain a conclusion to the experiment [3]. Secondly, students were required showcase creativity in how they would conduct the experiment to bring the desired goal. Lastly, enhancing the problem-solving abilities of students was a key goal for the experiment. By obtaining an expected and valid result, the experiment aids the development of an autonomous skill set to be used in other research projects conducted by other professors or researching students [3]. Furthermore, this project can be a part of a comprehensive program to advance the fluid mechanics knowledge of a student(s) where they may eventually incorporate more involved topics regarding fluid motion such as turbulence and losses of energy due to friction, pipe bends, valves, etc. [4]. The experiment will provide an educational setting that will help providing the student with a good foundation for fluid mechanics through an example that make uses of Bernoulli principle for incompressible fluids [5].

A prospective learner will be able to achieve a firm grasp of how the diameter of a pipe and water height affect the volumetric flow rate and that for the two studied pipe types with the same diameter size and height of water, the volumetric flow rate highly depends on the coefficient discharge value C_d [6]. The flow of water provides the optical evidence for the physical rate of flow. In addition, this experiment aims for students to use this experience to serve as a means to improve communication, research, and experimentation skills for future academic endeavors.

2. EXPERIMENT DETAILS

For this experiment, the team had purchased a 35-gallon plastic storage container from a hardware store to use as a water tank. With the use of a drill, the team was able to drill five holes into the 35-gallon storage box with the different sizes ½”, ¾”, 1” 1½”, and 2” team made sure that the holes were at least six inches apart and at least 4 inches from the bottom of the tank to prevent the tank from breaking. Once the five holes were drilled, the team used a male adapter to connect a polyvinyl chloride valve to control the flow of water.

Using these drilled holes, the team decided to apply an epoxy glue to attach the male adapters with valves to the tank openings. The epoxy glue had enabled a seal to form along the ring of the pipe opening, created from the drilled hole to prevent leaking. The team made sure that there was a generous amount of epoxy glue applied to each opening to make sure there was no leakage (Figs. 3 and 4). Then the team attached a 90° elbow pipe to the same sized valve and observed how the Q and C_d values changed with the assortment of sizes and observed how the Q and C_d values changed with different diameter sizes.

Figure 3: *Tank before epoxy putty application*

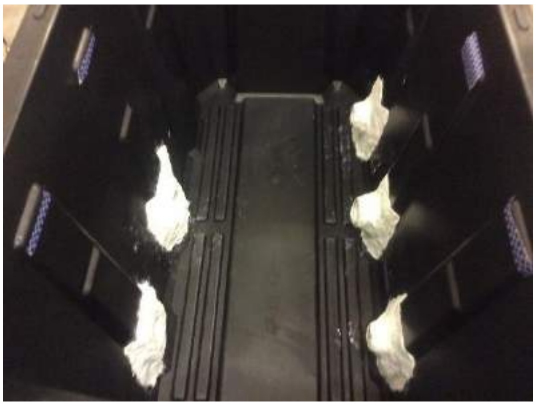


Figure 4: *Inner tank sealed with epoxy putty*

The team was faced with a problem of ensuring that the tank had no leakage. After the first trial of the experiment, the team discovered that the tank had a leaking issue. The team attempted to fix the issue and had discovered that using an epoxy putty would allow the team to create a seal that would be strong enough to prevent any leakage from the tank.

To conduct the experiment, the team made sure that the tank was placed on a leveled surface, checked if all of the values were closed, and then the team filled it with 31 gallons of water. The tank was marked at the 31-gallon line to ensure that in case there was any water loss the team would know how much water would need to fill the tank to ensure that it contains 31-gallons. The team placed a larger container at the bottom to catch the water which allowed the team to reuse the water for multiple tests to promote being more environmentally friendly by conserving water as shown in (Fig. 5).

Figure 5: *General setup of experimental apparatus*

The team had used the same procedure as the 90° pipe elbow fittings for the curved pipes and recorded the time for the tank to empty (Fig. 6). The experimental data was recorded after each time trial for each pipe specimen.

Figure 6: *Test run of 2-inch 90° pipe elbow*

Using the 90° pipe elbow fitting, the team opened the valves to discharge the water (Fig. 6) and started the stopwatch simultaneously. The team recorded the time for the tank to empty and then repeated these steps for the rest of the diameter sizes. Once the team finished with the 90° pipe elbow specimens, the team tested the curved pipes.

3. DISCUSSION OF RESULTS

The experimental values and data collected by the team throughout the experiment helped determine the coefficient of discharge, C_d. Eq. (1) derived Eq. (2), and it allowed for the experimental calculation of the coefficient of discharge. The team had obtained all the necessary data to solve for C_d values; area of the tank, height of the water level at which the tank was filled up to, area of the orifice, and the gravitational acceleration. Eq. (3) describes the volumetric flow rate (Q) as the relationship of volume of water discharged over time.

$$t = \frac{\left[(2\times A_t)(H)^{\frac{1}{2}}\right]}{\left[C_d \times A_o(2\times g_a)^{\frac{1}{2}}\right]} \qquad (1)$$

$$C_d = \frac{\left[(2\times A_t)(H)^{\frac{1}{2}}\right]}{\left[t \times A_o(2\times g_a)^{\frac{1}{2}}\right]} \qquad (2)$$

where A_t, H, C_d, t, A_o, and g_a are defined as the area of the tank, height of the water level in the tank, coefficient of discharge, water discharge time, area of the orifice, and gravitational acceleration (386.1 in/sec), respectively.

$$Q = \frac{V_d}{t} \qquad (3)$$

Tables 1 and 2 show the results obtained for the curved pipe and 90° elbow pipes, respectively. The results show that different pipe diameters produce different values of coefficient of discharge. Moreover, the variation for volume flow rate is also seen to be increasing as the diameter of the pipe increases.

Table 1. *Experimental data for curved pipe*

Diameter (in.)	C_d	Height of water (in.)	Δ Drop (in.)	Δ + H Total Ht. (in.)	Volume (in^3)	Time elapsed, (s)	Volume Flow rate, (in^3/s)	Pipe Area (in^2)
0.50	1.003	13.60	4.50	18.10	6,237	717	8.699	0.196
0.75	0.577	13.60	5.50	19.10	6,237	569	10.961	0.442
1.00	0.513	13.75	6.00	19.75	6,237	366	17.041	0.786

Table 2. Experimental data for 90° pipe elbow

Diameter (in.)	C_d	Height of water (in.)	Δ Drop (in.)	Δ +H Total Ht. (in.)	Volume, (in^3)	Time elapsed, (s)	Volume Flow rate, (in^3/s)	Pipe Area (in^2)
0.50	0.593	13.50	2.25	15.75	6,237	1,132	5.510	0.196
0.75	0.682	13.25	1.75	15.00	6,237	427	14.607	0.442
1.00	0.435	13.75	2.25	16.00	6,237	389	16.033	0.786
1.50	0.233	13.60	2.25	15.85	6,237	321	19.430	1.768
2.00	0.188	13.70	2.50	16.20	6,237	226	27.597	3.143

Fig. 7 shows the trends of the C_d values of a 90° elbow fitting and a curved pipe. The lines in Fig. 8 show the case where the 90° pipe and a curved pipe have the same volumetric flow rate. At this diameter, the curved pipe has a faster volumetric flow rate than the 90° elbow fitting.

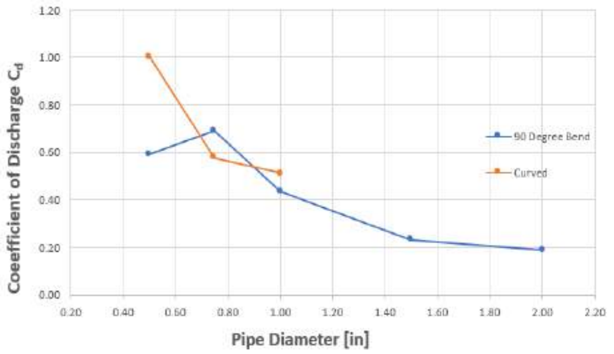


Figure 7. *Experimental data: coefficient of discharge vs. pipe diameter graph*

The relationship between coefficient of discharge and the pipe diameter is shown in Fig. 7. Generally, it can be observed that there is a gradual decrease of coefficient of discharge values as the diameter increases. The graph shows evidence of the inversely proportional relationship between the coefficient of discharge and the pipe diameter.

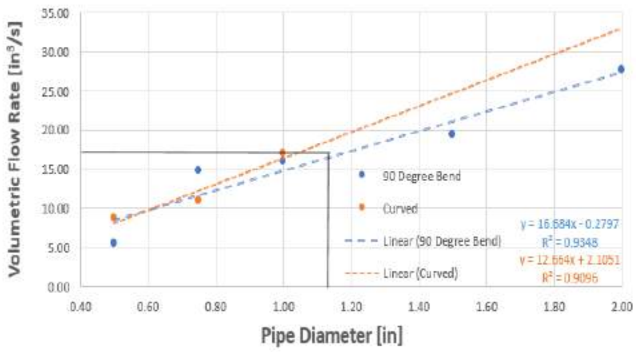


Figure 8. *Experimental data: graph of volumetric flow rate vs. pipe diameter for 90° elbow and curved pipes*

Fig. (8) shows the relationship between volumetric flow rates varies with pipe diameter. The graphical curves for the 90˚ elbow bend (R^2 = 0.9348) and the curved pipes (R^2 = 0.9096) cross at two different points. A linear relationship between the two parameters is observed in which the volumetric flow rate is increasing with increasing diameter sizes of the pipe. However, in either case, the shape of the graphs shown are not exactly straight lines.

4. EDUCATIONAL OBJECTIVES

The procedure and conditions of this experimental setting provide students with a good introductory fluid mechanics example which applies the Bernoulli principle for incompressible and non-viscous fluids moving along a streamline onto the gravitational discharge of water from a tank. The exit velocity of the water is known from Evangelista Torricelli's speed of efflux equation for a free water jet [7]. The results obtained from this experiment can verify that the volumetric flow rate is affected by factors such as the theoretical velocity, coefficient of discharge, and area of the pipe diameter [8].

By performing the experiment, students can investigate the speed of the water discharging from the different pipe types and diameters to attain the visual evidence which could aid in the development of a logical set of reasoning(s) to be used to justify the consequent values for the average volumetric flow rates of the water discharge. The physical outflow of water can help students acquire a more concrete understanding and intuition of how the differences of the area of the pipe diameter affect the resulting magnitudes of the volumetric flow rate for each pipe and orifice specimen. Subsequently, after the values of Q are determined, students can further investigate the factors, which compose the average volumetric flow rate such as the coefficient of discharge, area of the orifice outlet, and the speed of efflux [6,8,9].

The learning about the coefficient of discharge (C_d) is another learning objective gained through this experiment. It is determined by the geometric shape of the orifice opening. C_d has a positive value between zero and one. After conducting the experiment, students will be able to have a better understanding of the average volumetric flow rate due to its dependence on the C_d value, area of the orifice opening, and the average velocity of the water that is flowing outwards from the tank.

When avid fluid mechanics students obtain a firmer grasp of these concepts and how they affect the volumetric flow rate, then they may proceed to incorporate more involved topics regarding fluid motion, such as minor and major losses of energy due to pipe bends, friction, etc. and the laminar and turbulent behaviors of fluids by analyzing their different Reynolds numbers to allow for a more thorough investigation of how these concepts are related to the motion of a fluid through an outlet orifice [6,7,8].

Engineering students can enhance their undergraduate education by applying the knowledge that was learned in the classroom through a fruitful undergraduate research experience. The skills that are needed to complete the experiment may not be available through the academic setting alone. By partaking in undergraduate research, students have the opportunity to acquire, employ, and/or strengthen their own unique skill sets to contribute to the success of the project. The experience will expose students to participating and working as a coordinated team. The collaboration as a team that adapts and overcomes obstacles for the purpose of accomplishing a common goal is a significant undergraduate experience for students to have prior to their graduation. It can provide an opportunity for students to work with a variety of ethnicities and genders, not only for the duration of the project, but extending from the university and beyond into the world.

5. CONCLUSION

This experiment helped the participating students to visualize some class material, learned during the water resources module. Throughout the course of this project, the students involved had faced many challenges, such as: i) water leaking from the apparatus, ii) time restraints due erroneous leakage data, iii) divergence of ideas between the teammates, etc. Despite the challenges, the team had learned to work together in order to overcome those issues and obtain a satisfactory end result.

The practice of research and the undergraduate exposure to experiments provides an avenue for the students themselves to be able to engage in problem solving activities. It gives them the opportunity to use their creativity, problem-solving skills, and team work to strengthen the comprehension of engineering concepts. By doing this, the students are able to produce ideas for potential projects, which can become real inside the classroom. The successful completion of smaller-scaled projects and ideas like this, are the very things that inspire all students to become the successful engineers of tomorrow.

It is important to mention that performing experimental research as an undergraduate student, helps the student to develop the necessary skills needed, not only in the engineering field, but also in life. Exposing students to these kinds of activities, teaches them to communicate effectively, work in teams to share possible project ideas, build that project, learn from encountered obstacles, and perform the adjustments needed to complete the project with a successful conclusion. At the same time, the participants learn to coexist as one group and as one idea, by incorporating a diverse student population, welcoming and including the participation of women's ideas into the engineering field, and all the while promoting the co-existence of many different ethnicities.

ACKNOWLEDGEMENT

The student research team would like to take this opportunity to thank their instructors, Dr. Tadeh Zirakian and Dr. David Boyajian, Professors of Civil Engineering in the Department of Civil Engineering and Construction Management at California State University, Northridge, for the guidance that they have offered throughout this experimental study. The corrections that were made by the instructors provided an opportunity for group members to re-examine the work to perform the essential and necessary changes required to complete the study properly. Most importantly, a sincere appreciation must be given to every group member for the tireless efforts that had led to this successful study. The group is also grateful for the moral support that friends and relatives had given to allow for the completion of this report in a successful, timely manner.

REFERENCES

[1] Shortlidge, E. E., Bangera, G., & Brownell, S. E. (2015). Faculty Perspectives on Developing and Teaching Course-Based Undergraduate Research Experiences. *BioScience, 66*(1), 54-62. doi:10. 1093/biosci/biv167

[2] AERA Convenes Undergraduate Student Education Research Training Workshop. (2010). *Educational Researcher, 39*(6), 490-492.doi:10.3102/0013189 x10378604

[3] Carter, D. F., Ro, H. K., Alcott, B., & Lattuca, L. R. (2015). Co-Curricular Connections: The Role of Undergraduate Research Experiences in Promoting Engineering Students' Communication, Teamwork, and Leadership Skills. *Research in Higher Education,57*(3), 363-393. doi:10.1007/ s11162-015-9386-7

[4] Lee, J., Lu, T., Sun, H., & Miao, G. (2010). A novel formula to describe the velocity profile of free jet flow. *Archive of Applied Mechanics,81* (3)397402.doi:10.1007/s00419-010-0418-7

[5] Guerra, D., Plaisted, A., & Smith, M. (2005). A Bernoulli's Law Lab in a Bottle. *The Physics Teacher,43*(7), 456-459. doi:10.1119/1.2060646

[6] Hicks, A., & Slaton, W. (2014). Determining the Coefficient of Discharge for a Draining Container. *The Physics Teacher, 52*(1), 43-47. doi:10.1119/1.4849155

[7] Munson, B. R., Young, D. F., & Okiishi, T. H. (2012). *Fundamentals of fluid mechanics*. Hoboken, NJ: J. Wiley & Sons.

[8] Lindeburg, M. R. (2018). *Civil engineering reference manual for the PE exam*. Belmont, CA: Professional Publications

[9] Dziubiński, M., & Marcinkowski, A. (2006). Discharge of Newtonian and Non-Newtonian Liquids from Tanks. *Chemical Engineering*

ISSN 2455-4863 (Online) www.ijisset.org Volume: 5 Issue: 2 | 2019

Research and Design, *84*(12), 1194-1198. doi:10.1205/cherd.05138

AUTHORS' BIOGRAPHIES

Dr. Tadeh Zirakian

Assistant Professor in the Department of Civil Engineering and Construction Management at California State University, Northridge.

Dr. David Boyajian

Assistant Professor in the Department of Civil Engineering and Construction Management at California State University, Northridge.

Justin Le

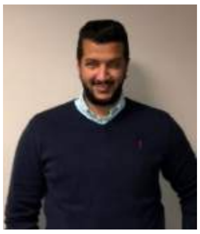
Undergraduate Civil Engineering student at California State University, Northridge.

Esraa Huseen

Undergraduate Civil Engineering student at California State University, Northridge.

Musaed Alkhurafi

Undergraduate Civil Engineering student at California State University, Northridge.

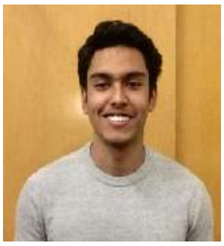


Naser Alrashoud

Undergraduate Civil Engineering student at California State University, Northridge.

Jonathan Perez

Undergraduate Civil Engineering student at California State University, Northridge.



Youssef Taher

Undergraduate Civil Engineering student at California State University, Northridge.

Mildred Renteria

Undergraduate Civil Engineering student at California State University, Northridge.