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Practical and Simple Laboratory Experiment to Visualize the Correlation among the Hydraulic Flow Parameters in Pipes

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Abstract: *The article presents the development and execution of a simple practical experience, which aims to help students of a civil engineering course, in a better understanding of the theoretical concepts involved in the topic of head loss in pressurized hydraulic conduits. Initially, a literature review is carried out, regarding the importance of practical classes in student training, laboratory practices, and experiments. Afterwards, the methodology used is presented, through measurement tests and the respective impacts on the flow rate, obtained by varying, one at a time, the length of the pipe, its diameters, and height between the water level in the reservoir and the water outlet point. The flow values varied as initially assumed. Finally, through the Fair-Whipple-Hsiao formula for small diameter plastic tubes, calculated flow values were obtained for each of the situations, and contrasted with the respective measured values. The results were considered satisfactory.*

Keywords: *Laboratory experiment, head loss, flow rate, college education, student engagement*

1. Introduction

One of the most challenging, yet crucial, components of good teaching is motivating learners. Student motivation is a key predictor of academic progress, involvement, and progress in higher education, resulting in improved academic performance and increased perseverance in the face of adversity. Despite the fact that there is a richness of motivational theories and lab results on student motivation, inspiring students in the classroom continues to be a difficult task. There is no practical assistance for putting theory into practice, leaving professors with the job of translating the extensive motivational literature into specific course design aspects [1].
It is described in [2] an attempt to understand the attitude of mathematics teachers towards Information Technology as an instructional tool, using the Technology Acceptance Model TAM framework. The results indicated that TAM, as a robust model, could be employed effectively in this context as well, and that a satisfactory match for the proposed model for the data was discovered. The sample consisted of solely high school mathematics instructors, who appeared to agree on the value of computers in mathematics instruction but were not very familiar with using them as teaching aids. This element contributes to the study's result that educators perceived ease of use has a substantial influence on their impression of usefulness and attitude toward the employment of technology in the classroom.
According to [3], some major features of educational apps are ease of access, simplicity, information quality, and a cheaper cost for a functional license. Because traditional commercial software is both costly and sophisticated, free and/or open source code may be a preferable alternative for teaching purposes.
In reference to laboratory activities in education, [4] emphasizes that understanding the events seen and how to interpret the data is a significant problem for students. However, it is apparent that the challenge is beneficial to the students and that they would benefit from the experience in their future studies.
Any laboratory's goal is to help people comprehend theory and practice better [5]. Lab courses may be adapted to include a heterogeneous approach that alters a student's learning experiences and enables a range of approaches in their practice with proper preparation and support. It is proposed that faculty investigate disassembly activities, computer simulation, and other free-form

exercises in addition to the usual instructor activities. Students can get a broader range of abilities and learn in more varied and deeper ways as a result. It is recommended that laboratories depart from regular operating procedures and investigate activity diversification, which can develop alternative modalities of information acquisition, hence enhancing students' interest and learning.
The tasks involved in activities carried out for a laboratory experiment [6], although sometimes relatively simple, are very effective in illustrating the effects of uncertainty on the quality of the results obtained. A pre-test instability assessment can show how inaccuracies in individual measurements might accumulate when utilized to calculate performance parameter values. An understanding of the consequences of mistakes might assist students in learning how to select proper instruments and testing processes. Because the testing is affordable and rapid, students may collect enough repeat measures to complete post-test statistical analysis. This post-test analysis may be contrasted to the pre-test instability assessment to offer a foundation for reflection on elements that were not expected, and thus suggest improvements to the test procedure that will result in improved quality measurements.
After mentioning potential rules that may manage the design and conduct of didactic labs in general, [7] explains how any of those systems could be applied to hydraulic labs. Reference [8] defines hydraulics as the engineering science that pertains to liquid pressure and flow. This study includes the manner in which liquids act in tanks and pipes, dealing with their properties and with ways of utilizing these properties. It includes the laws of floating bodies and the behavior of liquids under various conditions, and ways of directing this flow to useful ends, as well as many other related subjects and applications.
A large effort on learning styles and student involvement is described [5]. Much of the research implies that accomplishing these goals with a diverse student body requires a diversified approach to laboratory sessions. It is cited a study demonstrating that the inclusion of one extra method of learning resulted in better student engagement and performance in the subject of fluid mechanics and hydraulics.

2. Laboratory practices, experiments and the like

It is reported in [9] an experiment to determine the friction factor for a straight tube, with comparative analysis for different types of tubes. Reference [10] introduces a project to design and develop pneumatic laboratory activities for a course on Fluid Power, Mechanical Engineering. Various software packages were available for design, control and simulation of hydraulic, pneumatic, and motion control. The study relates safety rules, objectives, equipment, application, and circuit problems, for each laboratory. At the end, some conceptual questions are presented. It is discussed in [4] an experiment where data was acquired both manually and automatically in a fluid power laboratory.
The goal of the Civil Engineering design students was to illustrate the pneumatic movement of liquid water as it passes through an airtight one-way vessel system known as Heron's Fountain [11]. This study investigates hydraulic and pneumatic concepts often encountered in environmental control systems. Because this was a modest rendition of an ancient Greek fountain, its development required teamwork to carry out its simple function. The criteria involved were diameter, length, height, and density. This study employs Pascal and Bernoulli's equations to emphasize fluid mechanics ideas. The fountain action is represented by flow rate, while head loss is described by Darcy's equation. Reynolds' equation describes friction loss with an angled fitting attached to a fountain head. The research looked at the performance of two kinds of reentrant pipe fittings for head loss: straight and angled. The experiment improved the study team's educational experience by bringing together unique ideas from various academic and cultural contexts.
References [12] presents a fluid mechanics and hydraulics lab manual where, among several experiments, a practice that analyzes the relationship between major head losses and flow velocities for hydraulically smooth tubes, and the relationship between the friction factor and the Reynolds number for hydraulically rough tubes, is described. Similar description happens in [13], reporting an experiment to measure friction losses in pipes.
As illustrated in [14], a hydraulic laboratory course was designed to enhance water engineering students' understanding and knowledge of experimental methods and the basic principle of fluid

mechanics and apply those concepts in practice, while reference [15] describes a then newly implemented and innovative laboratory experience which was centered on a hydraulic position control system.
As expressed in [6], a laboratory exercise based on the performance testing of tiny drinking water pumps is demonstrated. According to the author, it offers a flexible and cost-effective environment for teaching the fundamentals of industrial experimental testing techniques to engineering technology students. Following on from that, this activity would give a practical opportunity for students to learn firsthand about the basic working characteristics of centrifugal pumps and highly associated components such as centrifugal compressors and fans.
A study was carried out to investigate the fluid flow and heat transfer features of microchannels. The hydraulic diameters of rectangular copper microchannels were 1.05 mm, 0.85 mm, and 0.57 mm. Heat transfer and head loss parameters were investigated in the laminar and transitional regimes using water as the work fluid and a constant surface heat flux [16].
Reference [17] describes a work whose major goal is to harmonize the multiplicity of criteria, formulas, tables, graphs, abacuses, images, and so forth in relation to hydraulic resistance coefficients. The study provides an equation that, accordingly, can be utilized to tackle a range of theoretical-practical difficulties that arise in hydraulics in general.
According to [18], understanding head losses in agricultural drainage facilities may be particularly useful both during the design phase to determine the best distance between drains and subsequently during the operating phase to track efficiency. It is presented a study based on the interpretation of data received in the lab and subsequently processed using specialist software engineering drainage system design.
A comparison of the hydraulic parameters, respectively flow rate and pressure, obtained on a physical model and estimated using the automated software for steady flow, RIMIS, is shown in [19]. The researchers developed a physical model to examine motion in a water distribution looping network. The comparative analysis seeks to validate the RIMIS software.
The results of an experiment on head loss and friction factor in small diameter polyethylene pipes are discussed in [20]. Five tubes were employed, with internal diameters of 10.0 mm, 12.9 mm, 16.1 mm, 17.4 mm, and 19.7 mm. The experiment was carried out for Reynolds numbers ranging from 6,000 to 72,000, acquired by varying the flow through the tubes at an average water temperature of 20ºC.
Reference [21] reports the findings of an experimental examination on flow-resistance law in small-diameter plastic pipes. Experiments were conducted over a broad range of Reynolds number values achieved by altering the discharge and water temperature. The experimental results are examined using both a purely empirical and a semitheoretical strategy, both of which are based on the supposition that the velocity profile has a power-law form.
Data on friction loss was obtained for three small diameter plastic tubes [22]. As per the research, a combination of the Blasius and Colebrook-White equations is then offered as an equation for the efficient and accurate prediction of head loss. According to the authors, the combination equation is still dimensionally homogeneous, correctable for viscosity changes, and accurate for small diameter plastic tubes.

3. Methodology

In order to solidify the theoretical foundations transmitted in the classes on the concepts of head loss in pressurized pipes, a laboratory experiment was carried out, with a view to better visualization and understanding of the correlations among the hydraulic parameters involved in the phenomenon of flow resistance.
The elaboration of the practice took place with simple acquisition materials, sometimes even disposable, with a very low assembly cost. Painted plastic paint buckets were used (simulating upstream reservoir) (Figure 1); acrylic groceries box (simulating downstream reservoir) (Figure 2); transparent garden hoses, 11 mm in diameter, 5.0 m and 8.2 m in length (simulating pipes); level hose, 8 mm in diameter, 5.0 m in length (simulating piping) (Figure 3); common garden hose (simulating pipeline to the upstream reservoir); box for material transport (simulating elevation of

the upstream reservoir, consequently, of the water level) (Figure 4). The described parts are shown in Figures 1 to 4.

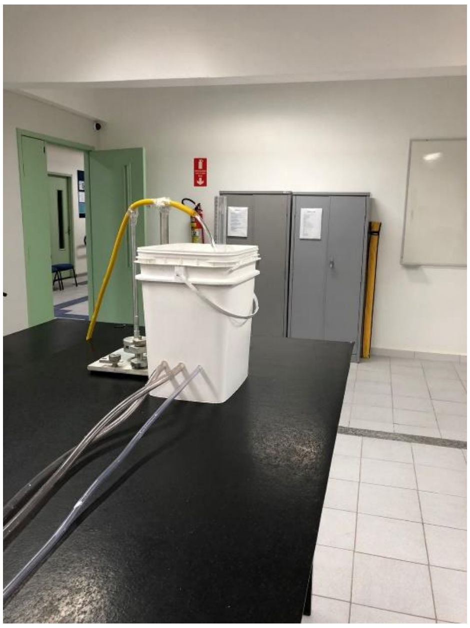

Fig. 1. Upstream reservoir

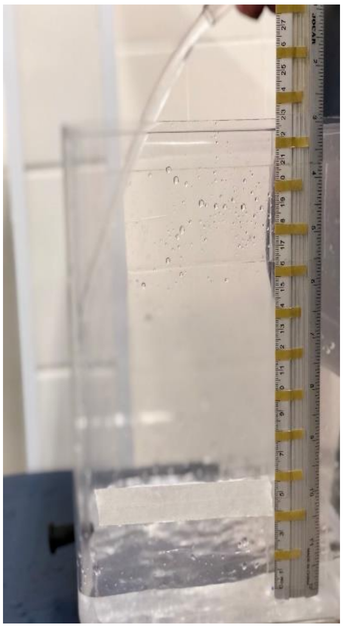

Fig. 2. Downstream reservoir

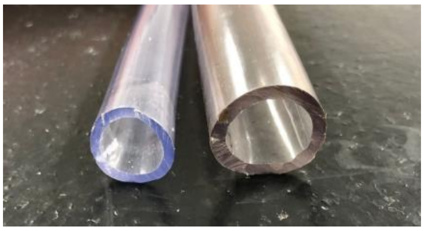

Fig. 3. Pipes

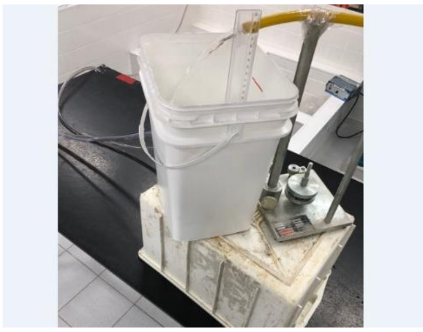

Fig. 4. Elevated reservoir

It is known that, based on transformations in the Bernoulli equation, one can assimilate the difference between the water level in the upstream reservoir and the water outlet to the atmosphere, at the other end of the pipeline, as the head loss, or part thereof. Equation (1) expresses the universal Darcy-Weisbach formula for head loss in pressurized pipelines.

$$h_f = \frac{8\,f}{g\,\pi^2} \cdot \frac{Q^2\,L}{D^5} \tag{1}$$

Where h_f is the head loss (m), f is the friction factor (dimensionless), g is the gravity acceleration (m/s^2), Q is the flow rate (m^3/s), L is the pipe length (m), and D is the pipe diameter (m).
From an analysis of (1), even though the friction factor f is not constant, it can be verified, in the first instance, that the flow rate Q varies directly with a power of the variation of the head loss h_f and of the diameter D, and that it varies inversely with a power of the change in length L.
Thus, 04 hydraulic combinations (or hydraulic situations) were taken, physically simulated one at a time, consisting of h_f, L and D, and, for each of them, the time to fill the volume of 3.0 L was measured in the downstream reservoir. This resulted in a flow rate for each of the situations. It was then possible to verify that the measured flow rates behaved as expected.
After this step, in order to get around the issue of the variability of the friction factor f of the Darcy-Weisbach formula as a function of the flow velocity, of the diameter itself, of the kinematic viscosity of the fluid and of the internal asperities of the tube wall, it was taken the Fair-Whipple-Hsiao formula for small diameters plastic tubes, also well known, expressed in equation (2).

$$Q = 55.934 \cdot D^{2.714} \cdot J^{0.571} \tag{2}$$

Where J is the head loss gradient, or hydraulic slope (= h_f / L), (m/m). The other quantities have already been defined previously.
At that moment, the flow rate values for each hydraulic situation were calculated using (2), based on the diameter of each situation and the head loss gradient, which consists of the ratio between the head loss and the length, in each situation. It is important to mention that the total energy (levels difference) were relatively small, so that the kinetic energy of the Bernoulli equation could not simply be neglected as a function of the total energy, which could generate inaccuracies. Therefore, the value of the kinetic energy (as a minor head loss) was deducted from the difference in level to result in the major head loss, which is the energy available to generate flow rate.

4. Results and discussion

Table 1 illustrates the combinations of the hydraulic parameters of each situation, as described in the previous section. It presents the flow rate values measured by volumetric process, and calculated by (2). Finally, the modular percentage deviation between the measured and calculated flow rate values is presented.

Table 1: Correlation of hydraulic parameters in pressurized pipes

Case	L (m)	D (mm)	ΔH (cm)	Q_M (10^{-6} m^3/s)	E_k (cm)	J (m/m)	Q_C (10^{-6} m^3/s)	dm (%)
1	5.0	11	56.0	72.9	3.00	0.1060	75.1	2.9
2	8.2	11	56.0	62.5	2.21	0.0656	57.1	9.1
3	5.0	8	56.0	31.0	1.94	0.1081	32.0	3.1
4	5.0	11	83.0	103.0	5.99	0.1540	92.9	10.3

L: length; D: diameter; ΔH: level difference; Q_M: measured flow rate; E_k: kinetic energy; J: head loss gradient; Q_C: calculated flow rate; dm: modular percentage deviation from the mean

As it was a very simple construction experiment, without the use of materials that would give precision to the system, it was understood that the results were quite satisfactory. This resulted, in fact, in a greater engagement of students in the process as a whole, deepening their understanding and apprehension of the concepts presented.

5. Conclusions

The importance of laboratory activities in the training of students in engineering courses and in the technological area in general has been known for a long time. Such activities make it possible to materialize and practice the topics seen in the classroom, testing concepts and hypotheses, modeling situations to be experienced in the future, in professional life.
The practical class, in addition to helping to establish the theoretical content that often requires a certain degree of abstraction, favors the development of critical thinking and the ability to work in a team. In this way, it leads the student closer to the content, bringing him into the process, which ends up learning also through doing, expanding his scientific understanding of the phenomena verified in the classroom.
Along this line, the present article presented a simple laboratory experiment to help students visualize the correlation among hydraulic parameters in pressurized pipes.

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