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Pressure Measurement of Water Bottle with Different Heights

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ABSTRACT

The relationship between pressure and depth in a fluid column, as described by hydrostatic principles, is fundamental to fluid mechanics. This study aimed to investigate the effect of pressure at various depths on water jet behaviour, addressing the problem of visualizing and quantifying the dependence of pressure on fluid column depth. An experimental setup was constructed using affordable and safe materials, including a transparent plastic bottle, a water reservoir, and a ruler. Equidistant holes of uniform size were created along the vertical side of the bottle, which was filled with water to a marked level above the highest hole. The height of each hole relative to the water surface was measured, and the horizontal distance travelled by the water jets was recorded. The experiment was repeated multiple times to ensure accuracy and consistency. The results showed that the horizontal distance travelled by the water jets increased with the depth of the hole, confirming that hydrostatic pressure increases linearly with depth. This demonstrated a clear relationship between depth and pressure, as deeper holes produced stronger and farther-reaching jets. The experiment offers an engaging and practical approach to teaching fluid mechanics concepts, utilizing low-cost materials and simple procedures. It reinforces the theoretical understanding of hydrostatic pressure and highlights its applications in real world systems, such as pipelines, dams, and hydraulic devices. In short, we obtain the result from a different perspective at different heights which is 0.15 m, 0.10 m and 0.05 m. For pressure, we obtain the result with 1471.5 Pa, 981.0 Pa and 588.6 Pa for its different height. For velocity, this fluid flows with 1.72 m/s, 1.40 m/s and 1.08 m/s at different heights.

1. Introduction

A fundamental principle in fluid mechanics is the relationship between pressure and height, particularly when studying immobile fluids like water or air. As you go deeper or higher in a stationary fluid, the pressure increases because the weight of the fluid above it affects the pressure at any given position [1]. This experiment provides a straightforward and efficient way to examine how pressure changes with vertical location in a fluid by using a garbage bottle to measure pressure at different heights. This experiment seeks to observe and measure how the pressure of a liquid changes as the

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height of the liquid column changes. By measuring pressure at different fluid heights and simulating fluid behaviour in a container using a garbage bottle, we can better understand how pressure operates in real-life situations such as liquid columns, water towers, and atmospheric pressure [2].

1.1 Basic Principle

The basic principle of the experiment, is given by the formula below.

$$P = \rho g h \tag{1}$$

where ρ is the density of the fluid (in kg/m³), g is the acceleration due to gravity (9.81 m/s²), h is the height of the fluid column above the point of measurement (in meters) and P is the pressure at a given depth (in Pascals, Pa). According to this equation, pressure increases as fluid column height does, meaning that the deeper you go into a fluid, the higher the pressure you will experience. In the experiment, this relationship will be explored in more detail [3].

This experiment offers a useful method for investigating the effects of pressure in fluids at different elevations. It demonstrates the fundamentals of fluid statics in an understandable manner and reaffirms the idea that pressure increases with fluid depth. Additionally, the experiment promotes environmental awareness by reusing items that are typically thrown away, such as a garbage container, turning waste into a useful resource for scientific research [4]. This experiment provides a simple and efficient method of demonstrating the relationship between pressure and fluid height by measuring pressure at different heights using a garbage container. It strengthens understanding of fundamental fluid mechanics concepts and provides significant insights into the behaviour of fluids. This experiment is both ecologically friendly and informative because it uses ordinary items [5,6].

1.2 Theoretical Background

In fluid mechanics, pressure is an essential concept for understanding how fluids behave in different situations. The pressure inside a fluid is influenced by elements such as the fluid's density, gravitational pull, and the elevation of the fluid column. The basis for assessing pressure at various elevations is derived from essential concepts of fluid statics, especially hydrostatic pressure [7].

1.2.1 Hydrostatic pressure

Hydrostatic pressure refers to the pressure exerted by a fluid at rest [8]. In a column of liquid, the pressure at any given point is directly proportional to the height of the fluid above that point as shown in Figure 1. This relationship is governed by the following equation which is Eq. (1).

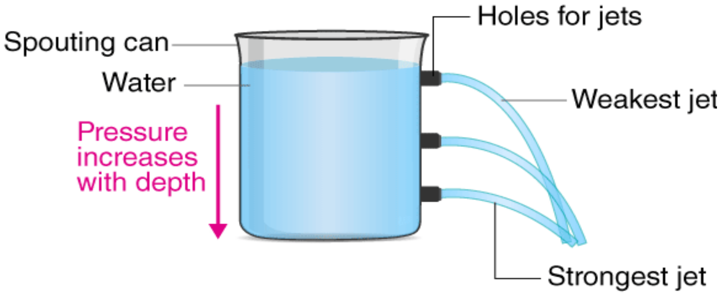


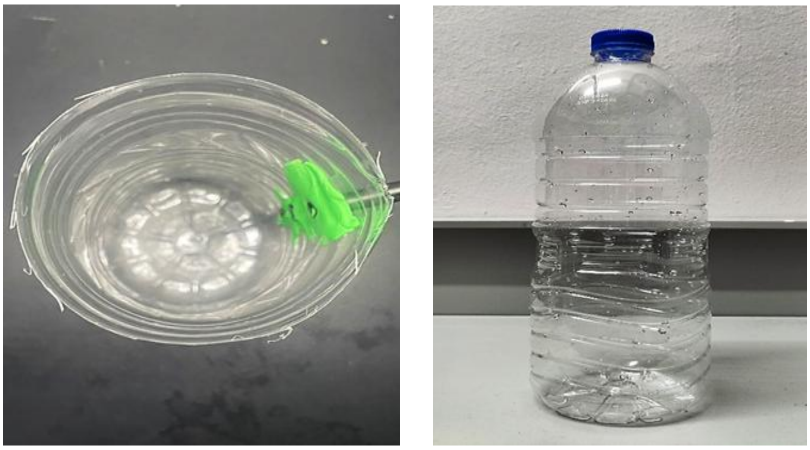
Fig. 1. Hydrostatic pressure experiment illustration

2. Methodology
2.1 Geometry of the Experiment

This section discusses the geometry of the experiment to obtain an accurate result. However, the experimental setup and the analysis from this study are discussed in the next sub-section.

2.1.1 Bottle height and water column

The experiment uses a 1.5-liter cylindrical bottle with a diameter of 0.08 m as shown in Figure 2. The bottle is filled to the top with water to provide a maximum water column height, ensuring sufficient pressure at all three holes. With the holes positioned at 5 cm, 10 cm, and 14 cm from the base, the water column above each hole changes during the experiment as water drains out. The cylindrical shape of the bottle simplifies calculations, as the hydrostatic pressure at each hole depends only on the height of the water column above it, given by Eq. (1), where h is the water column height.



(a) (b)

Fig. 2. Experimental apparatus (a) Diameter of the cylindrical bottle (b) 1.5-liter cylindrical bottle

2.1.2 Difference height of the holes

The placement of the three holes along a single vertical line on the bottle is critical to ensure consistency and accuracy. In this experiment, the holes are positioned at heights of 5 cm, 10 cm, and 14 cm from the base of the bottle as shown in Figure 3. These specific heights allow for easy correlation between the water column height and the resulting pressure at each hole. The diameter of each hole is 0.4 cm, ensuring consistent flow across all three points. Placing the first hole near the base and the others progressively higher ensures a measurable difference in jet strength due to varying water column heights. The chosen spacing simplifies data collection and analysis, particularly when plotting graphs to compare pressure, velocity, and jet range.

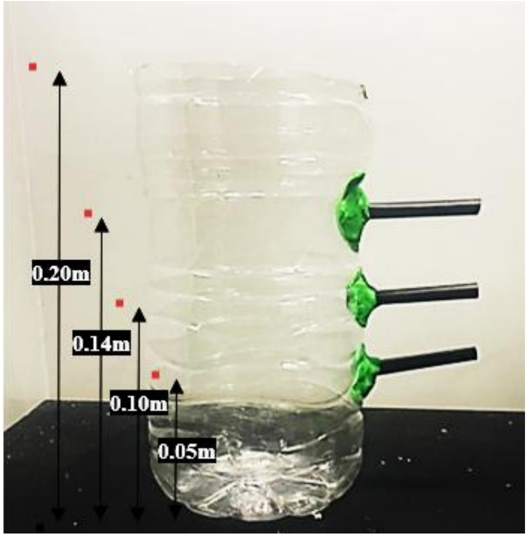


Fig. 3. Different height of the holes

2.1.3 Measurement of horizontal distance

To measure the horizontal distance of the water jets, a flat, horizontal surface such as a table or ruler is positioned parallel to the ground beneath the bottle as shown in Figure 4. The landing points of the jets are marked on this surface, and their distances from the base of the bottle are measured using a ruler. This horizontal distance is used to calculate the velocity of the jets using projectile motion equations. The setup ensures that the measurements accurately reflect the effect of water column height on jet range [9].

Fig. 4. Distance of the water jets

2.2 Experimental Setup for Pressure Measurement of Water with Different Heights

An experimental setup was designed and constructed to investigate the effect of pressure at different heights in a fluid column. The setup aimed to demonstrate the relationship between pressure and depth based on hydrostatic principles [10,11]. It included essential components such as a transparent vertical tube for measuring fluid height, a water reservoir as the fluid source, and a ruler to measure a different distance of the water jet [12]. The apparatus was constructed using affordable and safe materials, ensuring stability and precision during measurements. Below is Table

1 which shows the data collected from the experiment and the steps involved in assembling and preparing the experimental setup:

i. Ensure the plastic bottle is empty and clean to avoid interference from residues.
ii. Inspect the bottle for any cracks or irregularities that might affect the flow of water
iii. Use a pin to create holes of equal size at different heights along the vertical side of the bottle and ensure the holes are evenly spaced and aligned in a straight column.
iv. Measure and record the height of each hole from the water surface.
v. Fill the bottle with water to a marked level above the highest hole.
vi. Observe how the water jets behave as they exit the holes.
vii. Measure the horizontal distance travelled by the water jet from each hole to where it lands.
viii. Refill the bottle and repeat the process at least twice to ensure consistency and accuracy.

Table 1
Data from the experiment

Height of the hole from the base, h (m)	Horizontal distance, d (m)
0.05	0.145
0.10	0.096
0.14	0.067

2.3 Analysis of the Experiment

This segment will discuss all the analysis that can be pointed out from the experiment. This experiment provides several opportunities for analysis and understanding key principles of fluid mechanics. These analyses will deepen our understanding of fluid mechanics concepts such as pressure, velocity and projectile motion.

2.3.1 Pressure-height relationship

Analyse how the pressure at each hole is directly proportional to the height of the water column above it. The pressure can be determined by using the formula from Eq. (2).

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

where, ρ is the density of the fluid, g is gravitational acceleration and h is the height of the water above the hole.

2.3.2 Velocity of water jets

The relationship between velocity, v and height, h can be confirmed by comparing the velocities from different heights [13]. The velocity of water exiting each hole can be measured using Torricelli's Law as Eq. (3).

$$v = \sqrt{2gh} \tag{3}$$

where, v is the velocity, g is the gravitational acceleration and h, is height.

2.3.3 Horizontal distance of water jets

Measure how far each water jet travels horizontally, d and analyse how this depends on the height of the water column [14,15]. This can be defined using the projectile motion equation as shown in Eq. (4) and Eq. (5).

$$d = v \cdot t \tag{4}$$

$$t = \sqrt{\frac{2h}{g}} \tag{5}$$

where, d is the horizontal distance of the water jet, h is the height of the hole, v is the velocity and t are the time for the water to hit the ground.

2.3.4 Flow rate

Flow rate is defined as the quantity of fluid that is passing through a cross-section of a pipe in a specific period of time. It is the volume of fluid per time the fluid has flowed. Analyse the flow rate, Q of the water from each hole using Eq. (6).

$$Q = A \cdot v \tag{6}$$

where, A is the cross-sectional area of the hole.

2.3.5 Jet trajectory

The parabolic trajectory of the water jets can be analysed and validate the Eq. (7) of motion.

$$h = \frac{1}{2}gt^2 \tag{7}$$

2.3.6 Experimental errors

The experiment is subject to several sources of error that can affect the accuracy of the results. First, the geometry of the bottle poses a challenge since a mineral water bottle does not have a perfectly cylindrical shape. Variations in the bottle's diameter along with its height may cause deviations in pressure calculations, as the assumption of a uniform cylindrical shape influences the relationship between water height and pressure [16]. Second, the water pressure exiting the holes cannot be directly measured using a manometer pressure gauge, as such devices are typically designed for measuring high-pressure substances. This limitation requires the pressure to be inferred indirectly from calculations, introducing potential inaccuracies. Lastly, air resistance acting on the water jets can affect their trajectories and reduce their horizontal distance [17]. Although this effect is minimal for short ranges, it becomes more pronounced for higher jets, making it difficult to precisely compare theoretical and experimental results. Addressing or accounting for these errors during analysis is crucial for improving the experiment's accuracy.

3. Results

3.1 Pressure vs Height

This graph in Figure 5 demonstrates the relationship between the water column height above each hole and pressure at the point of water exit. The data in Table 2 which was obtained using hydrostatic pressure formula Eq. (2) states that pressure is directly proportional to water column height. The graph indicates that the pressure grows linearly with the height of the water column. This finding underlines the relevance of water depth in creating sufficient pressure for jet action [18].

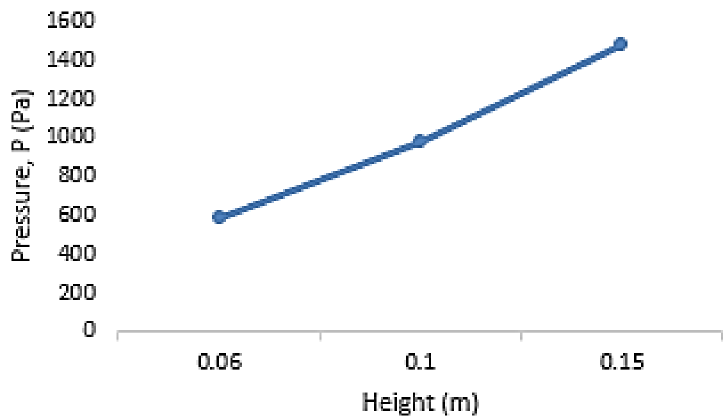


Fig. 5. Pressure vs height

Table 2
The value of the height and the pressure

Height of the hole, h; $h_{total} - h_{hole}$ from base (m)	Pressure at the hole, P (Pa)
0.15	1471.5
0.10	981.0
0.06	588.6

3.2 Velocity vs Height

The graph in Figure 6 shows how the velocity of water escaping through the holes varies with water column height. The data in Table 3 which get from Torricelli's Law Eq. (2) shows that exit velocity increases with water column height. This is because the increased height generates greater pressure, which is transformed into kinetic energy, increasing velocity [19]. The upward trajectory is non-linear, as velocity is proportional to the square root of height.

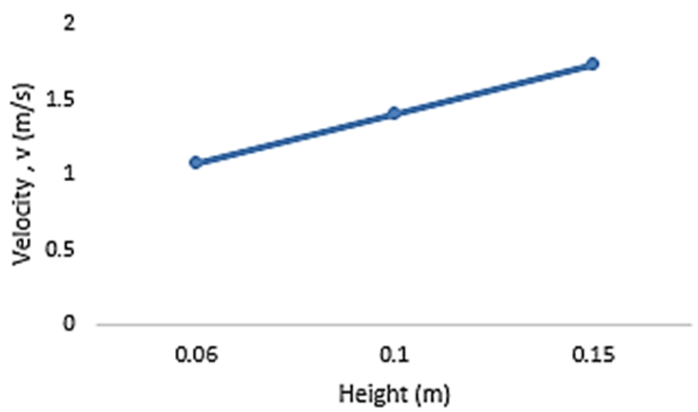


Fig. 6. Velocity vs height

Table 3
The values of the height and the velocity

Height of the hole, h; $h_{total} - h_{hole}$ from base (m)	Velocity at the hole, v (m/s)
0.15	1.72
0.10	1.40
0.06	1.08

3.3 Horizontal Distance vs Height

The graph in Figure 7 presents the relationship between the height of the water column and the horizontal distance (jet range) that it travels. The range is influenced by the jet's exit velocity and flight time. As the water column height rises, so does the range due to the increased exit velocity. This indicates a direct relationship between pressure-driven velocity and the horizontal reach of the jet [20]. Table 4 shows the data for measured horizontal distance and the calculated one which using Eq. (4) and Eq. (5).

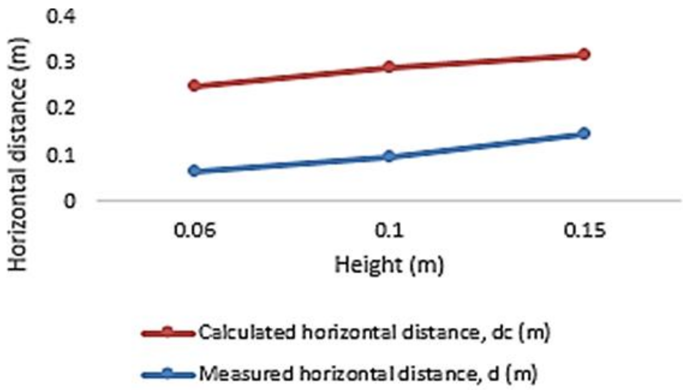


Fig. 7. Horizontal distance vs height

Table 4
The values of the height and the horizontal distance of the water jet

Height of the hole, h; $h_{total} - h_{hole}$ from base (m)	Measured horizontal distance, d (m)	Calculated horizontal distance, d_c (m)
0.15	0.145	0.172
0.10	0.096	0.196
0.06	0.067	0.184

3.4 Flow Rate vs Velocity

The graph in Figure 8 shows the relationship between flow rate (Q) and velocity (v) for a hole with a fixed diameter of 0.4 cm. It reveals a linear trend. As velocity increases, so does the flow rate. Table 5 is explained by Eq. 5, where (A) is the cross-sectional area of the hole. The line starts at the origin, meaning that when the velocity is zero, there is no flow. The slope of the line represents the hole's cross-sectional area. Larger diameters would result in steeper slopes because they allow for higher flow rates at the same velocity. This relationship shows that the flow rate is directly affected by the exit velocity of the fluid. Based on the results obtained above, the different height of holes gets different results from various perspectives such as height, horizontal distance, flow rate and velocity. The result shows 1471.5 Pa, 981.0 Pa and 588.6 Pa at the heights 0.15 m, 0.10 m and 0. 06 m. This result shows the relationship between the pressure and height is directly proportional, increasing the height will lead to the pressure increase at the same time and this also obeys Bernoulli's equation.

From another result such as horizontal distance, the horizontal distance result shows 0.145m, 0.096 m and 0.067 m at three different heights (0.05 m, 0.10 m and 0.14 m). This condition occurs due to the increased height leading to the pressure increase and horizontal distance travelled increase also. Lastly, the flow rate and velocity at different heights also show the difference which is 1.36×10^{-5} m^3/s and 1.08m/s at 0.05m, 1.76×10^{-5} m^3/s and 1.40 m/s at 0.10 m and 2.16×10^{-5} m^3/s and 1.72 m/s at 0.15 m.

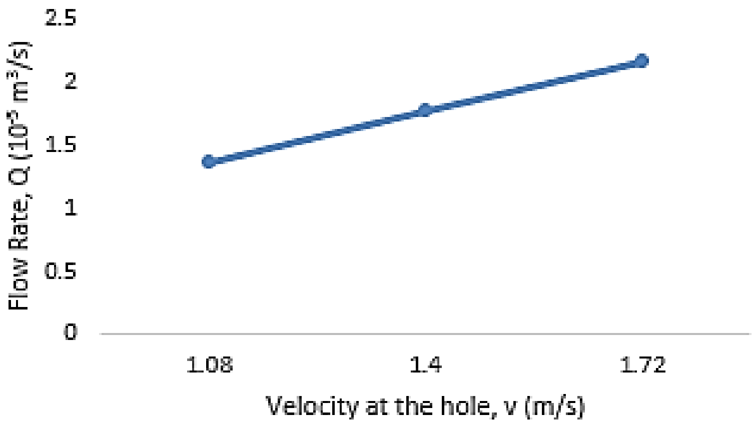


Fig. 8. Flow rate vs velocity

Table 5
The values of the flow rate and the velocity

Flow rate, Q (m^3/s)	Velocity at the hole, v (m/s)
1.36×10^{-5}	1.08
1.76×10^{-5}	1.40
2.16×10^{-5}	1.72

Based on the theory that we learned, the pressure of a fluid is related to the height (Bernoulli's equation). In this experiment, we use the different heights of the container to measure the pressure of the fluid and other effects such as horizontal distance travelled, fluid velocity and flow rate to verify. In the comparison with height and pressure, the graph shows a relationship directly proportional and it shows the experiment is successful and obeys the law applied. For horizontal distance travelled and height graph, it is also related to pressure and shows a graph directly proportional to the same as the theoretical graph. Lastly, the graph flow rate VS velocity is dependent on the relationship between the height and pressure also, when the height increases, the pressure increases at the same time, the flow rate will increase and the velocity also increases. This leads to the graph showing a relationship of direct proportionality. In short, this experiment became successful and obeyed Bernoulli's equation from the perspective of height and fluid and also velocity. This helped us to consolidate the knowledge we learned and know how to apply in real life.

4. Conclusions

In summary, the experiment aimed to measure the pressure and velocity of a fluid at different outlet hole heights (0.15m, 0.10m, and 0.05m) and analyze their relationship. The results showed that as the hole height decreased, both velocity and pressure also decreased, with recorded velocities of 1.72 m/s, 1.40 m/s, and 1.08 m/s, and corresponding pressures of 1471.5 Pa, 981.0 Pa, and 588.6 Pa. This outcome aligns with Bernoulli's principle, which explains the inverse relationship between fluid velocity and pressure, and Torricelli's theorem, which describes how fluid velocity is influenced by gravitational potential energy. Additionally, the pressure values correspond to the hydrostatic pressure equation, confirming the theoretical consistency of the results. The experiment successfully achieved its objective by accurately measuring and analyzing the relationship between pressure and velocity. The findings validate fundamental fluid mechanics principles, demonstrating that as the height of the hole decreases, both pressure and velocity decrease as expected. While minor experimental errors may have influenced the measurements, such as fluid turbulence or equipment limitations, the overall results align well with theoretical predictions, confirming the experiment's success.

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