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The Effect of Liquid Density on Fluid Flow Velocity in Bernoulli's Principle

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Abstract. This study aims to determine the effect of density on fluid flow velocity based on Bernoulli's principle and Torricelli's law. Density was varied by adding cornstarch to water with different concentrations, namely 0 kg, 0.03 kg, 0.06 kg, 0.09 kg, 0.12 kg, and 0.15 kg, at a fixed solution volume (1.5 liters). The experimental method used was a tool in the form of a perforated bottle placed at a fixed height, then the horizontal distance (x) of the first flow of the liquid was measured to calculate the velocity using the parabolic motion formula. Density was calculated from the ratio of mass to volume ($\rho=\frac{m}{V}$). The results showed that the higher the cornstarch content, the fluid density increased, while the flow distance and velocity tended to decrease. The increase in density was caused by the increase in solid particles in the solution which caused the flow to become slower because the driving force did not change. These findings indicate that density has a significant influence on fluid flow velocity, so it can be concluded that the greater the density of a fluid, the lower the flow velocity. This research supports the understanding that physical factors such as density need to be considered in real flow systems, both in education and engineering applications.

Keywords: fluid flow; velocity; density; cornstarch; Bernoulli's principle

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INTRODUCTION

Fluids are a type of substance that has the ability to flow and adjust its shape according to its container (Jalaludin et al., 2019). Fluids include two main forms of matter, namely liquid and gas, each of which has unique characteristics but both have the ability to flow (Thahir, 2018). Unlike solids, the particles that make up fluids are loosely arranged and do not have a fixed position, allowing them to move freely around each other. This condition causes the fluid to be able to adapt to the shape of the container it occupies and move from one place to another when subjected to external forces. a. The existence of fluids can be found in everyday life, for example, the flow of water in household pipes, air moving as wind, the use of water pumps, cooling systems, to hydraulic systems in heavy equipment. Not only in everyday life, the concept of fluids is also the basis for various fields of science and technology such as civil engineering, machinery, aviation, and medicine (Romdani, 2024)

Understanding the various phenomena related to fluid flow requires an in-depth study of fluid dynamics, which is the study of how fluids move and interact with their environment, which is one of the fundamental aspects of physics. Bhirawa (2017) stated that fluid flow is influenced by various factors, such as viscosity (the level of viscosity of a substance), pressure, flow velocity, cross-sectional area, and resistance of the channel surface. Fluid flow can be studied through Torricelli's law, which states that the rate of fluid flow from a hole is influenced by the height of the liquid surface above the hole. According to Nuraeni et al. (2020) the higher the position of the liquid surface, the greater the potential energy it has, so the flow velocity is also higher. Torricelli's law is a derivation of the Bernoulli equation which describes the relationship between pressure, velocity, and potential energy in fluid flow. The basic principle of Bernoulli assumes an ideal fluid without taking into account factors such as viscosity or mass. In reality, fluids, especially liquids, have various different characteristics, so they have the potential to affect the pattern and velocity of liquid flow (Pratama et al., 2022).

The difference in viscosity in fluid experiments is one of the important variables in influencing fluid flow during experiments. Sjarif et al. (2021) stated that the greater the concentration of dissolved solids in a liquid, the viscosity of the solution tends to increase due to increased interactions between particles in the liquid medium. One thing that can be done to increase the concentration of solutes is to add cornstarch. Cornstarch has solid particles that are spread throughout the liquid and have the ability to bind water (Puspitasari et al., 2018). Therefore, although no direct measurements of the viscosity level are carried out, the addition of cornstarch is expected to increase the viscosity of the solution. The viscosity of a liquid can affect its density, because changes in viscosity are often related to the concentration of dissolved particles which also have an impact on increasing mass per unit volume (Lita, 2021).

In Bernoulli's principle, to determine the effect of density on fluid flow, viscosity variations can be carried out by adding different cornstarch with the same volume of solvent in each experiment. Density can be determined by calculating the mass of the mixture of water and cornstarch divided by the volume of the solvent used. Sami (2016) stated that increasing the density of a liquid can affect its flow characteristics, because the denser the particles in it, the greater the internal resistance that may occur. This experiment sets the variation in density as a variable to determine whether it has an effect on the flow of liquid through a hole. The speed of the liquid flow in the experiment is calculated based on the distance the liquid falls for the first time horizontally from the container hole. To calculate the speed of the liquid flow, the formula is used:

$$v = \sqrt{\frac{x^2 . g}{2y}}$$

The formula is derived from the principle of parabolic motion and the concept of energy from Torricelli's Law derived from Bernoulli's principle, with g = acceleration due to gravity (9.8 m/s^2), x = horizontal distance of the liquid falling from the container, and y = height of the hole from the ground surface (Chusni et al., 2018). To maintain consistency of observations, the value of y is kept constant in all variations of the experiment, so that changes in flow velocity only depend on the density of the liquid. Based on this, the purpose of this experiment is to determine the effect of density on the flow velocity of liquids so that it can be analyzed that this characteristic is one of the important factors in fluid flow. If an increase in density has an effect on the flow velocity of liquids, then it can be assumed that density is an important factor in liquid flow. This research is expected to be not only useful in understanding the basic concepts of physics through contextual learning but can be applied in real life, for example, the selection of materials for fluid flow in pipes or channels.

METHOD

This study was conducted using an experimental method to determine the effect of density (rho) on the flow rate of liquids. The tools used include used plastic mineral water bottles (1.5 liters), iron and matches to make holes in the bottles, plasticine as a temporary stopper for the holes, a chair as a support, a meter to measure the horizontal distance of the flow, and a digital scale to weigh the mass of cornstarch. The materials needed are water and cornstarch as a solid substance that will be mixed into water with variations in cornstarch composition, namely 0 kg, 0.03 kg, 0.06 kg, 0.09 kg, 0.12 kg and 0.15 kg. Additional equipment such as spoons, bowls and kettles are used to mix the ingredients before pouring them into the mineral water bottles.

The experiment begins by making a hole in the bottle using an iron heated with a lighter and then the hole will be closed using a temporary stopper, namely plasticine. After that, a mixture of water and variations in the composition of cornstarch is put into the bottle until it reaches a total volume of 1.5 liters. Only 1 hole is made to see the consistency of the observation is only influenced by the viscosity of the liquid without varying y = the height of the hole from the ground surface. When the measurement begins, the plasticine is opened so that the liquid flows out through the hole. The horizontal distance x flow is measured with a meter. The measurement data are analyzed using the formula:

$$\boldsymbol{v} = \sqrt{\frac{\boldsymbol{x^2 . g}}{\boldsymbol{2y}}}$$

with x = horizontal distance and y = height of the liquid hole surface to the ground surface. Meanwhile, the density is obtained from the comparison of the mass of the mixture to its volume. The results of this calculation are used to see whether there is an effect of density on the speed of liquid flow.

RESULT AND DISCUSSION

This experiment aims to determine how changes in fluid density due to the addition of cornstarch affect the fluid flow rate based on Bernoulli's principle. Observations were made by mixing water and cornstarch in various concentrations, then measuring the mass, volume, and flow rate of each mixture. Observations were made using a simple tool made using a used bottle that was perforated with a nail, and using plasticine as a temporary cover for the hole.

In this experiment, six variations of solute concentration were carried out, by giving different levels of cornstarch to water with the same volume in each experiment. In each experiment, the distance of the first water flow (x) was observed, which was measured using a meter. The measurement started from the hole where the water came out to the point where the water first came out. The experimental data can be seen in Table 1. below:

Table 1. Experiment Results

Corn content (kg)	Distance x (m)	Volume (m^3)	Mass mixture (kg)
0	0,45	0,0015	1,5
0,03	0,44	0,0015	1,53
0,06	0,44	0,0015	1,56
0,09	0,43	0,0015	1,59
0,12	0,41	0,0015	1,62
0,15	0,40	0,0015	1,65

Based on the data in Table 1, it can be seen that the higher the level of cornstarch added to the water, the horizontal distance (x) of the fluid flow from the hole tends to decrease. The addition of cornstarch increases the number of solid particles in the solution, causing the viscosity of the fluid to increase. This increase in viscosity inhibits the movement of particles in the liquid, so that the flow becomes slower and the horizontal distance achieved is shorter (Sjarif et al., 2021). Because the flow velocity (v) is calculated based on the horizontal distance (x) and the height of the hole from the ground surface (y) using the principle of parabolic motion, a decrease in distance directly reduces the fluid velocity value (Chusni et al., 2018). On the other hand, the added cornstarch also increases the total mass of the mixture, while the volume remains the same, so that the density (ρ) increases according to the formula $\rho = m / V$ (Lita, 2021). The increase in density indicates that the particles in the fluid are getting denser, and this condition makes the fluid more difficult to move because it requires more energy to flow it (Kua et al., 2021). Therefore, it can be concluded that the cornstarch content plays an important role in influencing the characteristics of the fluid, namely by increasing the density and decreasing the flow velocity.

Then, based on the data above, further calculations can be carried out to obtain the values of fluid flow velocity (v) and fluid density (ρ). The first step is to calculate the flow velocity using the formula:

$$v = \sqrt{\frac{x^2 . g}{2y}}$$

where x is the horizontal distance of the fluid, y is the height of the hole from the ground surface which is 0.55 m, and g is the acceleration due to gravity (9.8 m/s²). After the velocity value (v) is obtained, the density of the fluid is calculated using the formula:

$$\rho = \frac{m}{V}$$

with m as the mass of the mixture in kg units and V as its volume which has been converted to cubic meters (m^3). The results of the calculation of speed (v) and density (ρ) are presented in Table 2. below:

Table 2. Results of calculating speed and density

Speed $(\boldsymbol{m/s^2})$	**Mass density** (ρ) $(\boldsymbol{kg/\,m^3})$
1,34	1000
1,31	1020
1,31	1040
1,28	1060
1,22	1080
1,19	1100

Based on table 2. above, the value of velocity (v) and density (ρ) can be analyzed to determine the relationship between density and fluid velocity in order to see the pattern of its relationship. Analysis can be done with a line diagram, which can be seen in Figure 2. below:

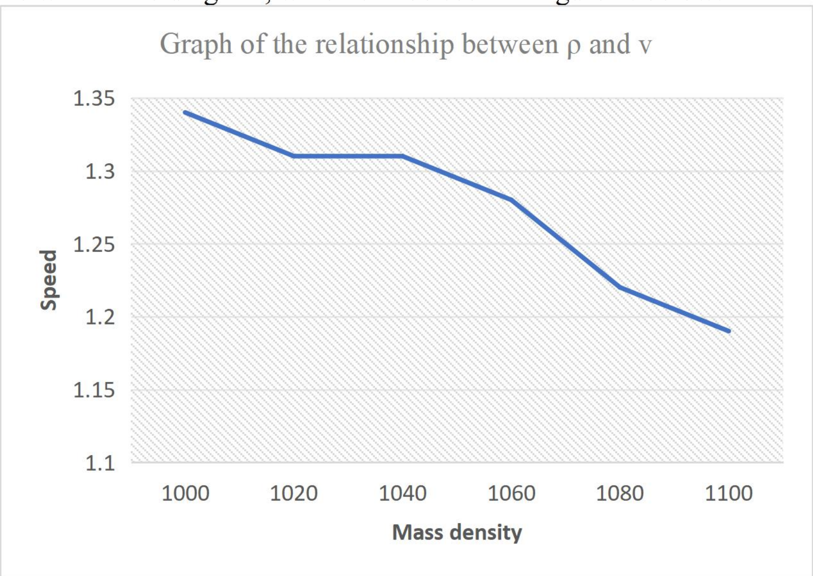

Figure 2. Graph of the relationship between ρ and v

Based on the graph above, there is a pattern that shows that the greater the density, the lower the flow velocity. This can be seen in the example of a density of 1000 kg/m³ which produces a speed of around 1.34 m/s, while when the density increases to 1100 kg/m³, the speed actually drops to only around 1.19 m/s. This decrease shows that there is an inverse relationship between density and fluid flow velocity. This relationship can be explained mathematically based on Bernoulli's principle, where the relationship between density ρ (rho) and velocity (v) of an ideal fluid can be derived from the equation:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

because during the practicum, the position of the container is open so that the pressure in the fluid is the same as atmospheric pressure. So the equation becomes

$$\rho g h = \frac{1}{2}\rho v^2$$

from the equation above, ρ (rho) on both sides can be simplified, so that it becomes

$$gh = \frac{1}{2} v^2$$

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

Based on the equation above, it proves that $v = \sqrt{2gh}$ is a derivative of Bernoulli's principle. To maintain the stability of energy in fluid flow, changes in ρ (rho) will affect the value of ν (velocity) because both have an inverse relationship. Density is an important property of fluids that affects velocity. According to Kua et al. (2021) fluids with higher density have higher particle densities, so they require greater force to move the particles. This causes fluids with higher density to flow more slowly when compared to fluids with lower density under the same driving force conditions. In addition, Nainggolan (2022) stated that fluids with higher density have greater inertia and make them more resistant to changes in velocity, so their speed will be slower in the flow system.

In the context of this experiment, the addition of cornstarch increases the concentration of solid particles in the solution, which directly affects the density of the liquid. Density is the ratio between mass and volume, so the greater the solute content, the higher the ρ value. Fluids with higher densities tend to be more difficult to achieve high velocities, because they require more energy (Sulthoni, 2016). If the driving force given is constant, then fluids with high densities will move slower than fluids with lower densities. Therefore, increasing density causes a decrease in the flow velocity of the fluid.

This finding shows that the physical characteristics of fluids, such as density, depend not only on the type of liquid, but also on the content of dissolved particles in it. In the context of learning physics, this understanding is important because it shows that the concept of fluids is not always ideal as assumed in Bernoulli's law. In practice, viscosity and density greatly affect the flow rate, as shown in this experiment. Applications of this principle can be found in various flow systems such as piping, irrigation channels, or fluid transportation systems in the food and pharmaceutical industries, where the regulation of density and viscosity is an important factor in maintaining optimal flow (Romdani, 2024).

CONCLUSION

This study shows that the addition of cornstarch to water affects the density and flow velocity of the fluid. The higher the cornstarch content, the higher the density of the solution, because the mass increases while the volume remains constant ($\rho = \frac{m}{V}$). This increase in density causes the flow to become slower, as indicated by the decrease in horizontal distance (x) when the fluid exits the hole. The flow velocity is calculated using the formula $v = \sqrt{\frac{x^2 . g}{2y}}$, so that a decrease in the x value indicates a decrease in the flow velocity. Thus, the greater the density of a fluid, the lower its flow velocity. This finding confirms that density is an important factor in fluid dynamics, which can be applied in various real-life flow systems, such as piping systems or fluid industries.

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