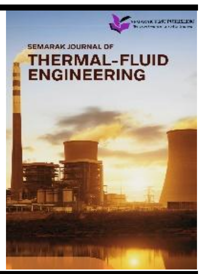
Semarak Journal of Thermal-Fluid Engineering

Journal homepage:
https://semarakilmu.com.my/journals/index.php/sjotfe/index
ISSN: 3030-6639



An Analysis of Egg Floating and Sinking in Fluids of Three Different Densities

Nurul Faresha Mohamad Yassir[1,*], Nur Iman Haiqal Roszaini[1], Nursyaza Adha Suhaihisam[1]

[1] Department of Mechanical and Manufacturing Engineering, Fakulti Kejuruteraan Mekanikal dan Pembuatan, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 10 April 2025
Received in revised form 2 May 2025
Accepted 15 May 2025
Available online 26 June 2025

Keywords:
Buoyancy; Archimedes' principle; floating; sinking; density

ABSTRACT

Buoyancy, as described by Archimedes' Principle, is the upward force exerted by a fluid that counteracts the weight of an immersed object. This study investigates how fluid density affects buoyant force by observing an egg's floating and sinking behaviour in three different fluids: plain water, saltwater, and a baking soda solution. The research aims to analysed the relationship between fluid density and an object's ability to float while demonstrating how changes in fluid composition influence buoyant force. The experiment involved preparing solutions with varying densities: plain water (1000 kg/m³), saltwater (1020 kg/m³), and a baking soda mixture (1100 kg/m³). An egg was submerged in each fluid, and its behaviour was recorded, particularly whether it remained fully submerged, partially submerged, or floated. The submerged height was measured, and buoyant force was calculated using Archimedes' principle. Increasing fluid density enhanced buoyant force, allowing the egg to float more effectively. In plain water, the egg fully submerged with a buoyant force of 1.96 N, which was insufficient to counteract its weight of 0.68 N. In saltwater, partial submersion was observed with a buoyant force of 2.04 N and its weight of 0.70 N. The densest fluid, the baking soda solution, generated the highest buoyant force of 2.50 N, causing the egg with its weight of 0.59 N to float higher. The experiment confirm that fluid density significantly affects buoyant force and an object's ability to float, aligning with theoretical expectations. These findings validate Archimedes' Principle by demonstrating that varying fluid densities have an impact on the buoyant force. Real-world implications extend to engineering, marine science, and fluid dynamics, particularly in understanding the floating mechanisms of objects and marine life in different salinity levels. The study highlights the importance of fluid properties in real-world applications and provides a simple yet effective approach to exploring fundamental physics principles.

1. Introduction

Buoyancy is a fundamental concept in fluid mechanics by describing the upward force exerted on the object immersed in a fluid as governed in Archimede's Principle this principle states that the buoyant force acting on an object is equals the weight of the fluid displaced by object as written by

* *Corresponding author.*
E-mail address: nurulfaresha7@gmail.com

https://doi.org/10.37934/sjotfe.5.1.110a

Bernt *et al.*, [1]. As the study of buoyancy and fluid dynamics often involves understanding the interaction between objects and liquid of different densities. Therefore, this experiment examine how fluid density affects buoyant force [2,3], this experiment showed the behaviour of an egg submerged in three different fluids of plain water, saltwater, and baking soda mixture. Regarding the topic, eggs were chosen as experimental objects due to their uniform geometry [4], which is measured by suitable device for its length and width [5]. The three fluids used in experiments have different density, achieved by dissolving different number of solutes, such as sodium carbonate (baking soda), sodium chloride (salt) in water. The variation of density allowed for the exploration in the principles of buoyancy whether it is entirely immersed, slightly submerged or floating which it has been introduced by Vella *et al.*, [6]. The height of water displacement measured that caused by the immersed eggs during the experiment which provides the quantitative understanding of how fluid density affects buoyant forces by Murat *et al.,* [7].

A fundamental concept of buoyancy in fluid mechanics describes the upward force applied to objects immersed in a fluid and the object's ability to float or sink [8,9]. This can be determined by using this force also known as buoyant force. According to Archimedes' Principle, the buoyant force acting on an object is equivalent to the weight of the displaced fluid. The object's behaviour is determined by the correlation between its weight and the buoyant force. The object floats when the buoyant force is greater than the weight and sinks when the weight exceeds the buoyant force. In other case, if these two forces are equivalent there will be no buoyancy, or it also can be called "zero buoyancy". This principle underlies various natural phenomena and engineering applications including floating icebergs, ships, and submarines. Buoyancy is also known for its primary element of density, which is defined as mass per unit volume, where the higher the density of fluids, the greater the buoyant force. For example, objects are more supported by seawater than freshwater because of the dissolved salts. In the same way, substances such as baking soda or salt increase the density of water, increasing the buoyant force and making it easier for objects to float.

This experiment investigates the behaviour of an egg in three different fluids with varying densities- plain water, salt water and a baking soda solution [10]. The other two fluids show how density changes affect buoyancy, having plain water serving as a baseline. Thus, the purpose of this study is to improve understanding of buoyancy principles while emphasizing the usefulness of fluid density in actual applications also to aim the deepen understanding of buoyancy principles and demonstrate the significance of fluid density in determine the object's ability to float or sink.

2. Methodology

2.1 Geometry of the Egg and Three Different Fluids

In this experiment, eggs were used as experimental objects with the dimensions that were measured before the experiment as shown in Figure 1. The dimensions for the first egg were measured with a length of 55.70 mm (5.57 cm) and width of 42.30 mm (4.23 cm) while the second egg had a length of 56.80 mm (5.68 cm) and width of 40.50 mm (4.05 cm) and the third egg measured a length of 57.83 mm (5.78 cm) and width of 43.70 mm (4.37 cm). The geometry of eggs needs to be taken into consideration since the volume has an impact on the interaction with the fluids displaced. On the other hand, the three different fluids used- plain water, salt mixture and baking soda mixture as shown in Figure 2. Each fluid has a various density resulting in a different buoyant force when the egg is placed.

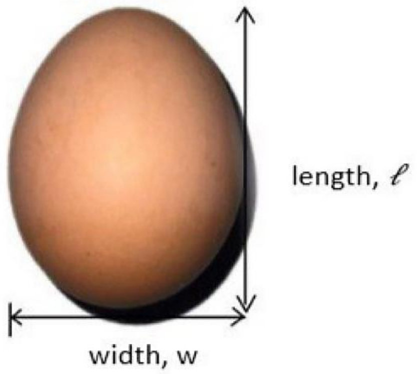


Fig. 1. Egg as the experiment object with measured width and length

(a) (b) (d)

Fig. 2. Fully dissolved solutions of the three different fluids (a) Water (b) Salt water (c) Baking soda

2.2 Experimental Setup

The preparation of this experiment to investigate the buoyancy of an egg in three different fluids began with the preparation of all the apparatus used. Three empty and clean 1000 ml beakers were prepared, and each beaker was labelled with “water”, “salt” and “baking soda” to differentiate the three different fluids. The egg was measured by using the vernier caliper as shown in Figure 3. to calculate the egg’s volume and weigh each egg using the analytical balance. The previously measured dimensions of the egg’s length and width were recorded as detailed in 3.1. Next, fill all the three beakers with plain water until it reaches approximately 600 ml and pour five tablespoons of sodium chloride (salt) and sodium bicarbonate (baking soda) into the designated beaker and mix well until the mixture is fully dissolved as shown in Figure 2.

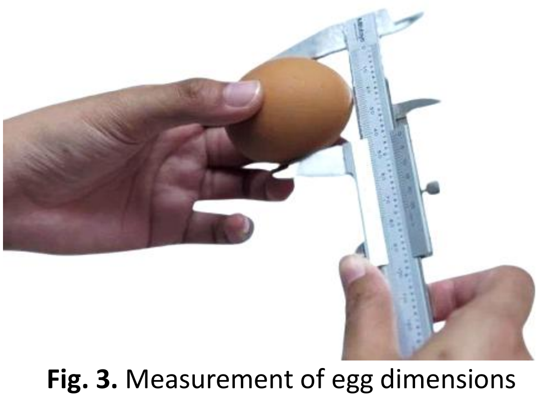


Fig. 3. Measurement of egg dimensions

Before the eggs were immersed in the beakers, the height of the fluids for the “Salt” and “baking soda” beakers were measured again after the addition of sodium chloride (salt) and sodium bicarbonate (baking soda). Thereafter, place three eggs into each of the three beakers of different fluids simultaneously where two beakers containing the prepared fluids as shown in Figure 4. The egg’s behaviour in each beaker was observed whether it is fully submerged, half-submerged or partially submerged. After the egg was added, the height of the submerged area of the egg was recorded for each beaker.

(a) (b) (c)

Fig. 4. Eggs simultaneously added into three beakers containing different fluids

2.2.1 Analysis for Buoyant Force

The height of the submerged area of the egg, $h_{submerged}$ is measured in this experiment to determine the buoyant force acting on the egg. This height is recorded at the end of the experiment since it influences the calculation for the volume of the egg’s submerged, $V_{submerged}$ which determined the buoyant force’s magnitude [11]. The relationship between the height of the submerged area and the volume of the submerged is expressed as:

$$V_{submerged} = A \, . \, h_{submerged} \quad (1)$$

where A represents the cross-sectional area of egg and $h_{submerged}$ represents the height of the submerged area of the egg in the fluid [12]. Other than that, based on the geometry of the egg’s, the cross-sectional area of the egg, A is calculated by using the formula:

$$A = \pi \frac{a \times b}{2} \quad (2)$$

where a is the width of the egg and b is the length of the egg since it is required to calculate the volume of the egg’s submerged, $V_{submerged}$. The buoyant force, F_B which is equivalent to the weight of the fluid displaced can be obtained by applying Archimedes’ Principle where the formula is:

$$F_B = \rho \, . \, g \, . \, V_{submerged} \quad (3)$$

where ρ represents the fluid density, g represents the gravitational acceleration and $V_{submerged}$ represents the volume of the egg’s submerged. By calculating all parameters, the experiment regarding the Archimedes’ Principles of buoyancy and floating can be validate and it shows the impact of different densities on the volume displaced and the buoyant force with the height of the submerged area of the egg, $h_{submerged}$ varying according to the density of the fluid.

The experiment uses three different densities of fluids including plain water, saltwater, and a baking soda mixture to examine the effects of the density of fluids to the buoyancy. The density, ρ of each fluid is expressed by using the formula:

$$\rho = \frac{m}{V} \tag{4}$$

where m represents the mass of fluid and V represents the volume of fluid. By examining the egg's behaviour in each fluid, the effects of the density of fluid towards the buoyant force and the height of the submerged area of the egg, $h_{submerged}$ can be analysed [13]. When the fluid is less dense, it produces a larger height of the submerged area of the egg, $h_{submerged}$ whereas denser fluids provide a lower larger height of the submerged area of the egg, $h_{submerged}$. The buoyant force relies on the weight of the displaced fluid based on Archimedes' Principle that is supported by these variations. The relationship between buoyant force and fluid properties can be verified by examining results for various densities.

3. Results and Discussion

This section discusses the results obtained from the buoyant force study. According to the results calculation, this experiment highlights the relationship between buoyant force, the density of fluids and Archimedes principle. Based on the area of eggs shown in Table 1, each of eggs has a different area which are calculated using Eq. (2) that the area of egg C is the biggest, followed by egg A then egg B, which has the smallest area among the 3 eggs. Therefore, the area will influence the volume of eggs and leading to higher buoyant force as mentioned by Othman *et al.,* [14].

Table 1
The mass and area of the egg

Egg	Mass (kg)	Area (m^2)
A	0.069	3.63×10^{-3}
B	0.071	3.58×10^{-3}
C	0.067	4.00×10^{-3}

The height submerged is observed after the eggs are dropped which also depending on the volume of the egg. Using Eq. (5) where a is the width of the egg and b is the length of the egg. The volume, submerged volume, height submerged and buoyant force for egg A, B and C are shown in Table 2.

$$V = \frac{4}{3}\pi \times a^2 \times b \tag{5}$$

Table 2
The volume, height submerged and buoyant force for each egg

Egg	Volume (m^3)	$h_{submerged}$ (m)	Buoyant force (N)
A	2.29×10^{-4}	0.055	1.96
B	2.26×10^{-4}	0.035	2.04
C	2.65×10^{-4}	0.057	2.50

Using Eq. (1) and Eq. (3), we obtained the buoyant forces for each egg and observed the differences for each behavior of the egg in different fluid densities. Egg C is partially submerged in baking soda solution, which has a density of 1100 kg/m³, obtained the highest buoyant force out of the three eggs calculated, which is 2.46 N. Egg A fully submerged into water, which has a density of 1000 kg/m³, has a buoyant force of 1.96 N and egg B was floating in saltwater, which has a density of 1020 kg/m³, has the least buoyant force of 1.25 N. Therefore, the density of fluid influenced whether the eggs were floating or sinking, as mentioned by Knutsen *et al.,* [15]. If the density of fluid exceeded the density of egg and the buoyant force is bigger than the weight of egg, it will allow the object to float as example for egg B and egg C [16,17]. While egg A is fully sinking into the water because of the density (1000 kg/m³) which the buoyant force was insufficient to fully balance the weight of the egg.

The graph analysis in Figure 5 shows a negative linear relationship between the buoyant force (N) against the mass of eggs (kg). As the mass of the egg increases, the buoyant force decreases which at the highest buoyant force is 2.46 N, the egg has the smallest mass of 0.067 kg which it is in the densest fluid such as baking soda. The lowest buoyant force is 1.25 N occurs in the largest mass of 0.071 kg, and it is in saltwater substance. The graph analysis of buoyant force (N) and the volume of egg (m³) as shown in Figure 6, at the lower buoyant forces of 0 until 2 N observed the volume of egg remain nearly constant which 0.000226 m³ which it indicates the stable fluid displacement in less dense liquids. However, on beyond 2 N buoyant force there is sharp increase in volume to 0.000265 m³ that reflecting a greater fluid displacement in denser solutions such as baking soda. The Archimedes principle is applied to demonstrates the experiment effectively, which states that the buoyant forces acted upward is equal to the weight of the displaced fluid [18,19]. Thus, the result and analysis validate this principle with the calculations of the buoyant force align with the measured densities of fluid and the area odd eggs also it provides the factors influencing floating and sinking behaviour [20].

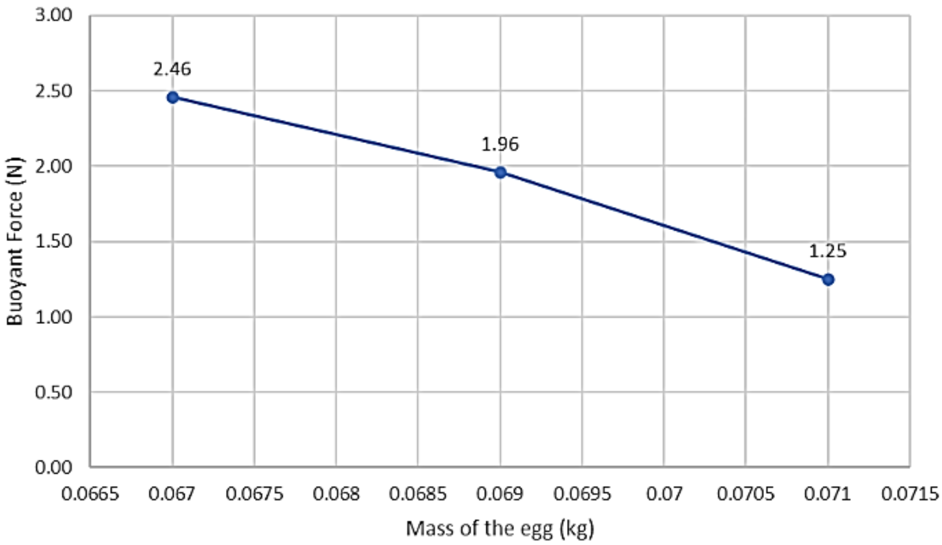


Fig. 5. The buoyant force of the egg vs mass of the egg in three different fluids

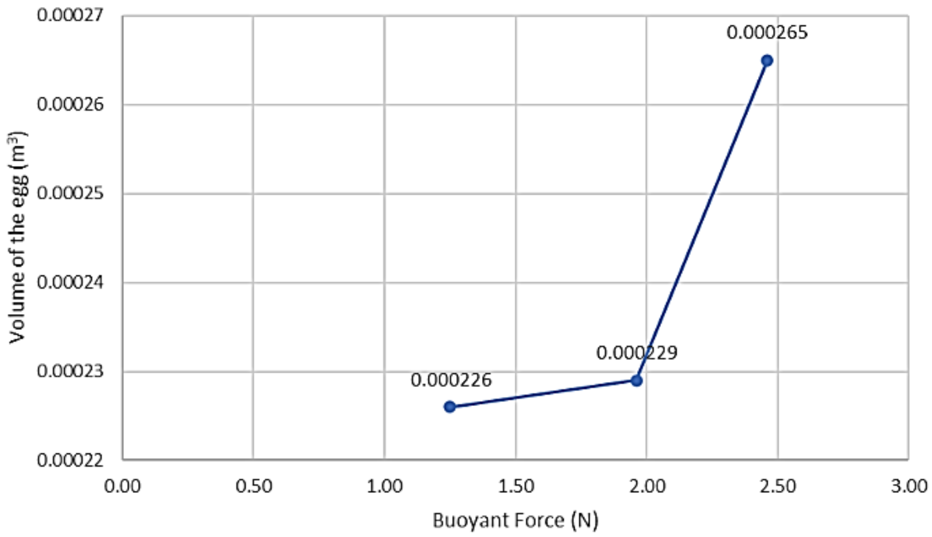


Fig. 6. The volume of the egg vs the buoyant force of the egg

4. Conclusions

This experimental study had found that all the floating or sinking objects will undergo buoyant force. Buoyant force can simply mean the upward force a fluid exerts on a body immersed in it. This case not only happens in liquid conditions, but it also can happen in air conditions. From the conceptual point of view, the buoyant force itself has included in calculation the of factors such as density of a fluid, volume of fluid that has been displaced, and acceleration due to gravity. According to Archimedes' Principle, we had derived the fact that the buoyant force exerted on an object is directly proportional to the volume of fluid that is being displaced and to the density of the fluid while it is independent of how deep the object has been submerged.

The analysis also confirms that an object will float, or sink based on the relationship between its weight and the buoyant force. If the buoyancy force exceeds the density of an object, then the object will float while if the buoyancy force is less than the density of the object, then the object will sink. Furthermore, understanding these principles has practical applications in various fields, including engineering, marine science, and fluid dynamics. Further studies could involve examining buoyant forces in different fluids and conditions or exploring how temperature and pressure affect fluid density.

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