SEMARAK ILMU PUBLISHING

Semarak Journal of Thermal-Fluid Engineering

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

Investigate How the Height Difference Affects the Flow Rate by Use Siphon System

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ARTICLE INFO

Article history:
Received 18 January 2025
Received in revised form 17 February 2025
Accepted 12 March 2025
Available online 27 March 2025

Keywords:
Siphon system; Bernoulli's equation; fluid dynamics; flow rate; elevation difference; Reynolds number

ABSTRACT

A siphon system is a simple yet fascinating example of fluid dynamics, where liquid flows from a higher reservoir to a lower one through a tube due to gravity and atmospheric pressure. A siphon system, governed by Bernoulli's equation, represents a practical application of fluid dynamics, enabling fluid transfer between reservoirs of differing heights without mechanical assistance. This study aims investigates the relationship between height difference and flow rate in a siphon system, utilizing two distinct fluids: water and oil. The research aims to bridge theoretical predictions and empirical observations, focusing on optimizing siphon performance in real-world applications. The experiment employed a siphon system consisting of a rubber tube with a fixed diameter 3.65 mm and length 50 cm. Measurements were conducted at five height differences 0, 5, 10, 15, and 20 cm. The flow rates were calculated as the volume transferred in one minute, with the cross-sectional tube area constant. Water and oil were used to examine the effects of viscosity and density on fluid dynamics. The results confirmed that as the height difference increased, so did the flow rate for both fluids. For water, flow rates ranged from 5.17 $\mu m^3/s$ at 0 cm to 11.3 $\mu m^3/s$ at 20 cm. In contrast, oil's flow rates were significantly lower, increasing from 0.133 $\mu m^3/s$ at 0 cm to 0.417 $\mu m^3/s$ at 20 cm. Based on the results, the higher flow rates of water are attributed to its lower viscosity compared to oil. Experimental velocity calculations aligned closely with theoretical predictions for water but deviated for oil, highlighting energy losses due to viscosity and friction. The study concludes that the height difference significantly influences siphon flow rates, with fluid properties such as viscosity and density playing critical roles. Water demonstrated superior efficiency for siphon systems, while oil required greater height differences to achieve comparable performance. These findings underscore the need to consider fluid characteristics when designing siphon systems for industrial and agricultural applications.

1. Introduction

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https://doi.org/10.37934/sjotfe.4.1.2534a

The last few decades have witnessed extensive research on fluid dynamics, particularly on systems involving the transfer of fluids through siphoning. Using the laws of gravity and atmospheric pressure, the syphon system is an amazing hydraulic device that makes it easier to move liquids from one place to another [1]. A siphon is a tube used to convey liquids from one level to a lower level, and the height difference between the two containers plays a significant role in determining the flow rate. Understanding this phenomenon is crucial for various applications, including irrigation systems, drainage, and industrial processes.

This study aims to investigate how the height difference between two containers affects the siphon flow rate using two different fluids which are tap water and oil. Bernoulli's principle provides a foundational explanation of fluid motion in siphon systems, as it links pressure, velocity, and height within a flowing fluid [2]. Further expanding on this principle, Roberts *et al.,* [3] was introduced the concept of "fluid potential energy" to explain siphon behaviour more comprehensively, particularly in cases where the fluid undergoes changes in velocity as it flows from a higher to a lower container. Roberts' work emphasizes the role of gravitational potential energy in determining the siphon's flow rate, reinforcing the significance of height differences in siphon efficiency. Detailed reviews on the factors influencing siphon flow rates, such as fluid viscosity and height differences, can be found in review papers by several authors [4-6]. These studies provide a comprehensive understanding of the underlying mechanisms and pave the way for the current investigation.

The operation of a siphon system can be explained using Bernoulli's equation, which relates the pressure, velocity, and elevation of a fluid along a streamline [7]. In a siphon, we consider two points which are the inlet submerged in the higher container and the outlet in the lower container. Assuming the fluid is incompressible and the flow is steady, Bernoulli's equation can be simplified since the pressure at both ends is atmospheric and cancels out. Additionally, the velocity at the inlet is much smaller compared to the outlet, so it can be neglected [8]. This results in an equation where the velocity of the fluid at the outlet is related to the height difference between the fluid levels in the two containers. Specifically, the fluid velocity at the outlet is proportional to the square root of the height difference [9,10]. This means that as the elevation difference between the two containers increases, the velocity of the fluid at the outlet also increases.

The flow rate, which is the amount of fluid passing through the siphon per unit of time, depends on both the outlet velocity and the cross-sectional area of the siphon tube. Therefore, increasing the height difference between the containers leads to a higher flow rate, as the greater gravitational potential energy difference accelerates the fluid more effectively.

2. Methodology

2.1 The Geometry of Tube and Two Different Fluids

In this experiment, the geometry of the rubber tube used for the siphoning process includes the dimensions of tube inner diameter was 0.00365 meters (or 3.65 mm) and the length was 50 cm shows in Figure 1. This specific diameter was selected to maintain a consistent and measurable flow rate throughout the experiment. Also, two different fluids were used in this experiment to observe how fluid type influences the siphon flow rate. The first fluid was tapping water, with a volume of 1000 ml, which served as the primary fluid in most of the trials. The second fluid used was oil, with a volume of 790 ml shows in Figure 2.

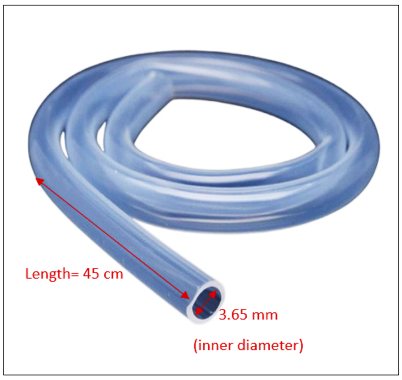
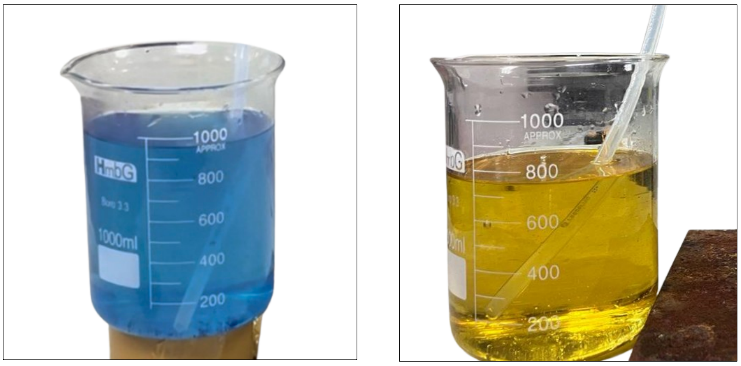


Fig. 1. Dimensions of rubber tube used for this experiment



(a) (b)

Fig. 2. Types of Liquids (a) 100 ml of tap water with blue water coloured (b) 790 ml of oil

2.2 Experimental Setup and Siphon System Process

First step of the experiment, set up the siphon system by connecting a flexible plastic or rubber tube between two beakers, referred to as Beaker A and Beaker B. Use a clamp or pinch clip to control the flow of liquid through the tube. Beaker A was filled with blue colored water and ensure that the tube's inlet and outlet are fully submerged, eliminating any air pockets. Next, position Beaker A at a fixed height on a retort stand and place Beaker B at a lower level. Adjust the height difference between the two beakers to five distinct levels, such as 0 cm, 5 cm, 10 cm, 15 cm, and 20 cm as shown in Figure 3**.**

Once the beakers are positioned, release the clamp or pinch clip to allow water to flow from Beaker A to Beaker B. Measure the volume of liquid transferred to Beaker B within a constant time for 1 minute and constant initial value using a graduated measuring beaker. Record the height difference, the volume of water transferred, and calculate the flow rate (volume/time) for the first height difference. Next, change the position of Beaker A to increase the height difference to the next level, repeating the previous steps for all five height differences. Repeat all the steps above with use oil as a substance of liquid. Ensure that variables such as the tube diameter, tube length, and liquid type remain constant throughout the experiment.

Fig. 3. Experimental setup by use the oil with 0 cm high elevation difference between two beakers

2.2.1 Analysis for the flow rate of the Siphon system

The flow rates, Q measures the volume of fluid that passes through a given point in a system per unit of a time which is a minute. The volume measured in the receiving beaker within a fixed time interval divide by the time interval to calculate the flow rate of the experiment and can be expressed as:

$$Q = \frac{V}{t} \tag{1}$$

where V is the collected volume and t is the time of duration taken for the measurement taken which is a minute. The experiment provided insights into the relationship between height differences and flow rate in siphon system for two different fluids, water and oil. This relationship of flow rate can be expressed as:

$$Q = A \times v_{experimental} \tag{2}$$

where Q is the flow rate (volume per time), A is the cross-sectional area of the tube, and v is the fluid velocity. Impact of height differences on flow rate on the experiments shows as the height difference increases, the flow rate increases. This finding aligns with Bernoulli's equation, which predicts the velocity of a fluid at the outlet is proportional to the square root of the height difference [11]. This indicates the theoretical velocities can be calculated using the derivation equation from Bernoulli's equation:

$$v_{theoretical} = \sqrt{2g(h_1 - h_2)} \tag{3}$$

where g is the acceleration due to gravity and h is the differential height between two beakers. While the theoretical velocities can be calculate using Eq. (3), the experimental velocities calculate using Eq. (2). Comparing these values revealed discrepancies, particularly for oil, due to unaccounted factors such as vicious losses and friction within the tube. For water, experimental velocities were closer to the theoretical predictions, reflecting its lower resistance to flow. The flow behaviours between water and oil are primarily influenced by their viscosities and densities.

The relationship between these properties and the Reynold number can be expressed in:

$$Re = \frac{\rho v D}{\mu} \tag{4}$$

where ρ is the fluid density, v is the velocity, D is the tube diameter and μ is the dynamic viscosity. the Reynold numbers values for water is higher than oil as the density of water is higher than soil confirming its flow is faster than oil due to its lower viscosity. This property makes water more efficient in siphon systems, while oil has a higher viscosity significantly hampers its flow [12]. The flow regime for both is determined by the Reynold number which below 2000 critical values are laminar flow, range between 2000 and 4000 is transitional flow and higher values than 4000 is turbulent flow. The lower the values of Reynold number indicating a slower and more viscous flow.

3. Results

3.1 Flow Rate of Water and Oil

This section discusses the results obtained from the siphon systems measurement study. The velocity of flow, theoretical velocity using Bernoulli's Equation are discussed in the next sub section. Thus, the measured results for this experiment are in Table 1.

Table 1
The measured volume and different heights with various density of fluid

	Volume measured in 1 minute, V (ml)				
Fluid	0 cm	5 cm	10 cm	15 cm	20 cm
Water	310	400	490	600	680
Oil	8	18	20	22	25

3.1.1 The effect of volume calculated in 1 minute

The test configuration for this experiment is in Table 2**.** Nevertheless, for the experiment at 1 minute, the volume collected in beaker B as the siphon systems. To differentiate the effects of volume and differential of height, the experiments was also performed at two different densities of fluid, ρ such as oil and water, 880 $\mathrm{kg/m^3}$ and 1000 $\mathrm{kg/m^3}$ that corresponding to 1 minute of experiment, calculated from Eq. (1) and summarize in Table 2.

Table 2
The values of flow rate and height of different

Height (cm)	Flow rate, *Q*	
	Water	Oil
0	5.17 $\mathrm{\mu m^3/s}$	0.133 $\mathrm{\mu m^3/s}$
5	6.67 $\mathrm{\mu m^3/s}$	0.267 $\mathrm{\mu m^3/s}$
10	8.17 $\mathrm{\mu m^3/s}$	0.333 $\mathrm{\mu m^3/s}$
15	10.0 $\mathrm{\mu m^3/s}$	0.367 $\mathrm{\mu m^3/s}$
20	11.3 $\mathrm{\mu m^3/s}$	0.417 $\mathrm{\mu m^3/s}$

3.1.2 The effect of flow rate with velocity

The velocity calculates with flow rate and area of the tube used in the experiment is in Table 3. The cross-sectional area of the tube remains constant with the tube diameter being 0.0365 m. To differentiate the velocity flow rate, the data of velocity for both substances was calculate using the formula of flow rate divide with tube cross-sectional area. The data calculated with Eq. (2), and summarized data in the Table 3.

Table 3
The velocity of the flow rate for oil and water

Height (cm)	Velocity, v (*m/s*)	
	Water	Oil
0	0.00494	0.000127
5	0.00638	0.000255
10	0.00781	0.000318
15	0.00956	0.000351
20	0.01080	0.000398

3.1.3 Theoretical velocity using Bernoulli's equation

The theoretical velocity is a little different than velocity of flow as it is using the Bernoulli Equation to derive its base. This helps to compare the theoretical velocity and the experimental velocity which can be determine as the velocity of flow. This theoretical value does not concern the effect of a fluid incompressible, energy losses and the steady of the flow. Table 4 shows the data of the theoretical value proportional to the differential height.

Table 4
The value of theoretical velocity

Height (cm)	Theoretical velocity (m/s)
0	0.00
5	0.99
10	1.40
15	1.72
20	1.98

The theoretical value for oil and water is the same as the Bernoulli's equation depends only on the height difference and gravity, not on the type of the fluid. This theoretical velocity can be calculated with Eq. (3) and summarized in Table 4.

3.1.4 Reynold numbers

The configuration for this experiment is in Table 5. Nevertheless, the for the experiment at the dynamic viscosity (μ) of oil and water is 0.1 Pa and 0.001 Pa, and the diameter of tube is constant with 0.0365 m.

Table 5
The Reynold numbers for oil and water

Height (cm)	Reynold numbers, Re	
	Oil	Water
0	0.42	180
5	0.84	233
10	1.04	285
15	1.15	349
20	1.31	394

The data from the Table 5 shows both of oil and water flow is laminar flow as the Reynold numbers for both is very low and under 2000. The Reynold number of oil is extremely low due to its high viscosity, confirming very slow laminar flow. This Reynold number calculate by Eq. (4) and summarized in Table 5.

3.1.5 Comparison graphical for theoretical velocity and velocity flow

The graphical for theoretical velocity and measured velocity is for comparing the gap distance between the two data. As the data stated in the table, it shows that the value for theoretical value and measured value has a big value of gap thus the graph line will be not visible as for oil. Below the Figure 4 shows the graphical of measured velocity vs height. Figure 5 shows all the velocity involve such as measured velocity and theoretical velocity proportional to the height for comparison between theoretical velocity and measured velocity. This highlights the discrepancies between the measured and theoretical velocities that indicate the importance of accounting other factors such as viscous forces, friction within the tube, incompressible flow and turbulences effects.

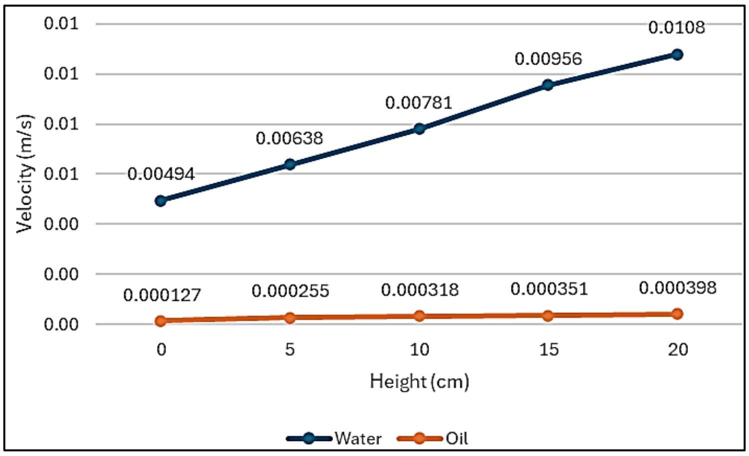


Fig. 4. velocity of oil and water vs height for analyzing systems efficiency

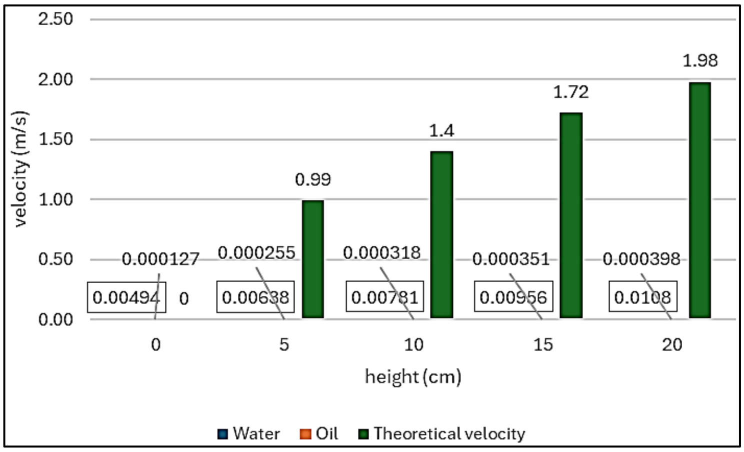


Fig. 5. Measured velocities of oil and water vs theoretical velocities

The Figure 6 shows the graph of the Reynold numbers of oil and water comparison with height. This graph helps to analyse the of scale of the transitional flow between oil and water. Graph Reynold numbers vs height contextualizes the fluid behaviour in terms of flow regime.

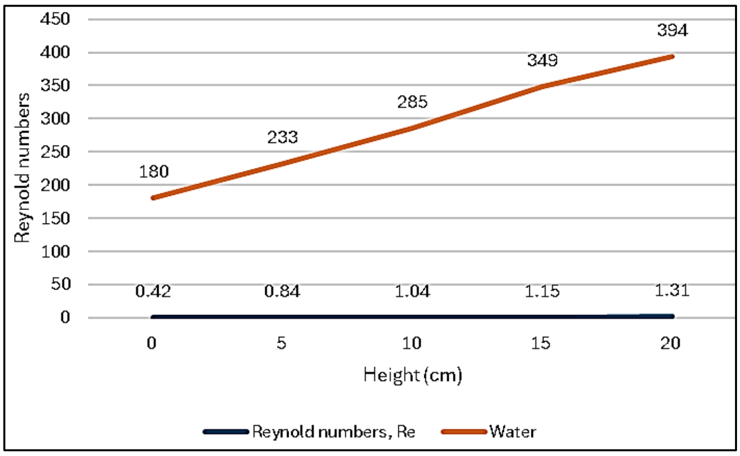


Fig. 6. Reynold number comparison between water and oil

4. Results and Discussion

The result of this study demonstrates the relationship between height differences, fluid properties, and the siphon systems performance, offering a practical validation of fluid dynamic principles and theoretical models such as Bernoulli's equation [13]. The data in Table 2 shows the as the height differences increases, the flow rate for both water and oil increases. This behaviour aligns with the analysis of theoretical predictions as the greater the height differences, the greater gravitational potential energy.

The information in Table 3 shows the velocity of flow rates for oil and water in a syphon system, emphasising the notable behavioural differences brought about by their different physical characteristics. At different heights, the computed velocities which are obtained by dividing the flow rate by the tube's cross-sectional area show that water continuously has higher flow velocities than oil. The velocity of water, reaches 0.0108 m/s at a height of 20 cm, whereas the velocity of oil is only 0.000398 m/s. Viscosity's effect on fluid dynamics in syphon systems is highlighted by this striking contrast.

Higher velocities are the result of water flowing more freely through the syphon tube due to its lower viscosity [14]. On the other hand, oil's higher viscosity results in increased internal resistance, which severely reduces its flow rate. Higher velocities for both fluids are a result of the gravitational force acting on the fluid increasing with the height of the liquid column. But in water, where there is less resistance to movement, the effect is much more noticeable and can sustain a more effective flow.

Moreover, theoretical understanding of the anticipated velocities of both fluids can be obtained by using Bernoulli's equation. The syphoning process demonstrates how Bernoulli's principle states that a fluid's velocity increases as its potential energy decreases. Lower observed velocities result from oil's inability to convert potential energy into kinetic energy as effectively as water due to its higher viscosity [15]. In Table 4 shows the theoretical velocities without accounting the factors such as viscous flow, friction on the tube and turbulence which amplifies the values of velocity compared to the measured velocity in Table 3. This shows the practical measured values consists of a lot of other factors in calculation that give a huge impact on the real values compared to the theoretical velocities which neglect a lot of factors during the flow of experiment.

The Reynold numbers in Table 5 show both oil and water are laminar flow as the critical values for both are under 2000. Oil indicates a slower laminar flow compared to water due to its high viscosity [16-18]. Lastly, the comparison graph shows in Figure 4, Figure 5 and Figure 6 shows huge differences between oil and water in each aspect such as measured velocities and Reynold numbers. This shows that water is more efficient in siphon systems compared to oil as the great difference gap between both shows the oil is not efficient and not practicable for siphon systems due to its high viscosity.

5. Conclusions

In conclusion, this experiment successfully investigated the relationship between height difference and flow rate in a siphon system using water and oil as test fluids. The results confirmed that the height difference between the reservoirs significantly impacts the flow rate, validating theoretical predictions based on Bernoulli's equation.

At the minimum height difference 0 cm, the flow rates for water and oil were 5.17 $\mu m^3/s$ and 0.133 $\mu m^3/s$, respectively. These low values highlight the limited gravitational potential energy available to drive the flow at minimal elevation differences. At the average height difference 10 cm, water exhibited a flow rate of 8.17 $\mu m^3/s$, whereas oil recorded a considerably lower flow rate of 0.333 $\mu m^3/s$, emphasizing the influence of viscosity. At the maximum height difference 20 cm, the flow rates increased significantly for both fluids, reaching 11.3 $\mu m^3/s$ for water and 0.417 $\mu m^3/s$ for oil. The 20 cm height difference resulted in a 118% increase in flow rate for water and a 213% increase for oil compared to the 0 cm height difference. This trend demonstrates the critical role of gravitational potential energy in enhancing fluid velocity and flow rate.

Water consistently outperformed oil across all height differences due to its lower viscosity, which minimizes internal resistance and energy losses. In contrast, oil's higher viscosity and lower density limited its ability to convert potential energy into kinetic energy effectively. These findings highlight that water is more suitable for applications requiring efficient siphoning, while oil demands greater height differences or system adjustments for improved performance.

In conclusion, the experiment confirmed that increasing height differences enhance siphon flow rates, with fluid properties such as viscosity and density significantly influencing efficiency. This research provides valuable insights for optimizing siphon systems in various practical applications, including irrigation, industrial fluid transfer, and petroleum engineering.

Acknowledgement
This research was supported by the Ministry of Higher Education of Malaysia through the Fundamental Research Garat Scheme (FRGS/1/2024/TK10/UTHM/02/6) and through MDR grant (Q686).

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