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RESEARCH ARTICLE

AN OBSERVATIONAL STUDY ON THE CONSTRUCTION AND FUNCTIONS OF A WATER CLOCK

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Abstract

This study examines the workings of a water clock and attempts to formulate alternatives while retaining the basic principles of Torricelli\'s law. There is thorough discussion on the history of water clocks, their different types and the apparatus required to model the functioning prototype. This is followed by a detailed explanation of the procedure undertaken for the construction of the alternate model. In the interpretation and results section, readings and observations measured through 18 different experiments are tabulated through charts and graphs, leading up to a summarized discussion in the conclusion.

Introduction:-

History and Background

Water clock is a simple device that is used to determine the time by measuring the rate of flow of water. Time keeping was vital in order to maximise agricultural output, perform rituals and conduct various other tasks efficiently. The earlier method of using the sun’s position was inaccurate, and ineffective on cloudy and rainy days. To counter this problem the water clock was developed. While the exact date is unknown it is said that the development of the first water clock known as clepsydra(translated as water thief in English) started as early as 325 BCE and they were commonly found in Egypt, Babylon, and Persia around the 16th century. It is said that the Greeks were the first to start using the water clock. However, a 16th century Egyptian official Amenemhet was said to be the first inventor of the water clock.

Types of water clocks

Outflow Water Clock:

A hole is made in the container and water is allowed to flow into another vessel. Decrease in the water level of the initial container is used to determine the change in time. Example: If the water level in the initial Container drops by 2 centimetres in 1 hour, then if the water level drops by 8 centimetres we can predict that 4 hours have passed.

Inflow Water Clock:

A hole is made in the container and water is allowed to flow into another vessel. The increase in water level of the second vessel used to determine the change in time Example: if the water level in the secondary vessel rises by 2 cm in 1 hour, then if the water level rises by 8 cm we can predict that 4 hours have passed.

Image from: https://www.alamy.com/stock-photo-water-clock-clepsydra-56753442.html

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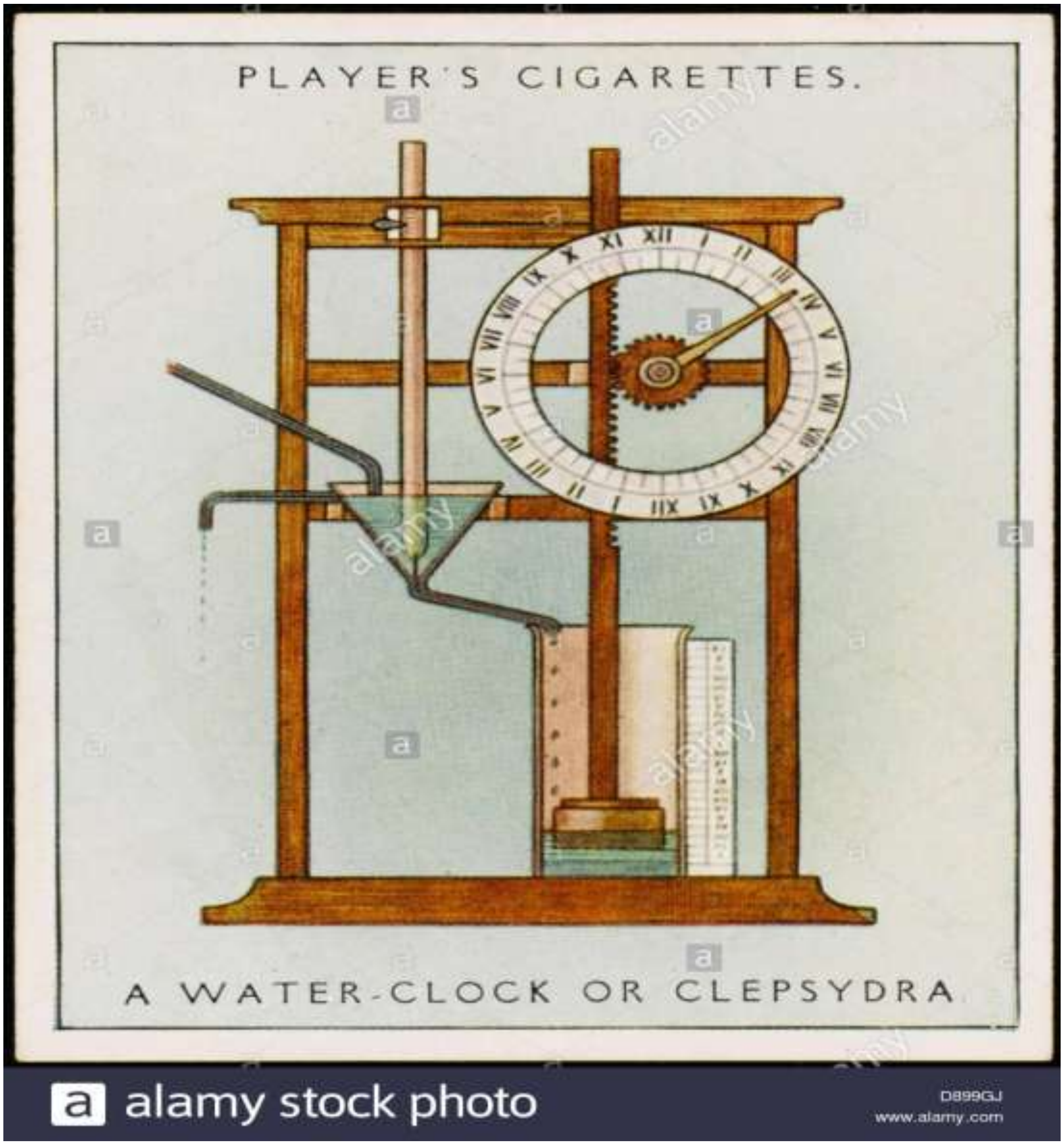
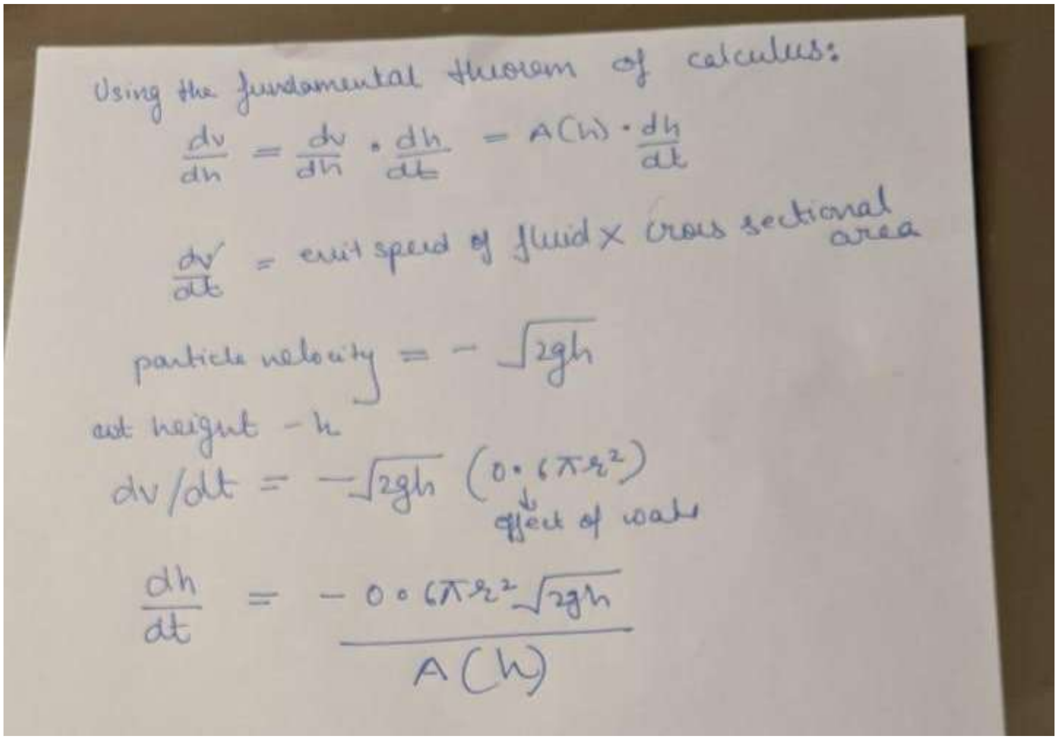
Basic principle
The basic principle behind the working of any water clock is the torricelli's law. The law deals with the flow of water from an orifice(small hole) and its velocity under gravity with respect to the height of water above the orifice. The rate of flow of water was used to measure time.



The importance of Torricelli ̒s Law
Evangelista Torricelli was a famous mathematician and physicist born in Italy in 1608. He is famous for discovering the principle behind a barometer and it was his work on the velocities of fluids with respect to their height that forms the principle behind the functioning of the water clock.

His law established that the rate at which water flows from the primary container is directly proportional to the height. The chain rule helps us in finding the rate of change of volume.

From Torricelli's law we know that the particle velocity is $-\sqrt{2gh}$. When the height of the water is 'h', area at that height is A(h), and the radius of the container is 'r' then:


Using the fundamental theorem of calculus:

$$\frac{dv}{dh} = \frac{dv}{dh} \cdot \frac{dh}{dt} = A(h) \cdot \frac{dh}{dt}$$

$$\frac{dv}{dt} = \text{exit speed of fluid} \times \text{cross sectional area}$$

particle velocity $= -\sqrt{2gh}$

at height $- h$

$$dv/dt = -\sqrt{2gh}\ (0.6\pi r^2)$$

effect of wate

$$\frac{dh}{dt} = \frac{-0.6\pi r^2\sqrt{2gh}}{A(h)}$$

Construction of the water clock:

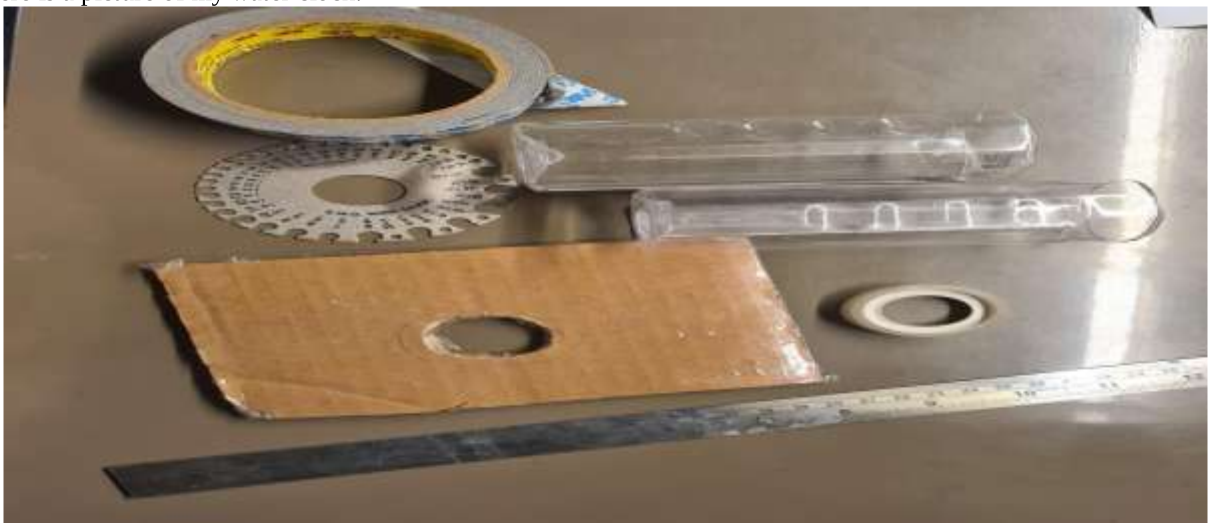
Apparatus:

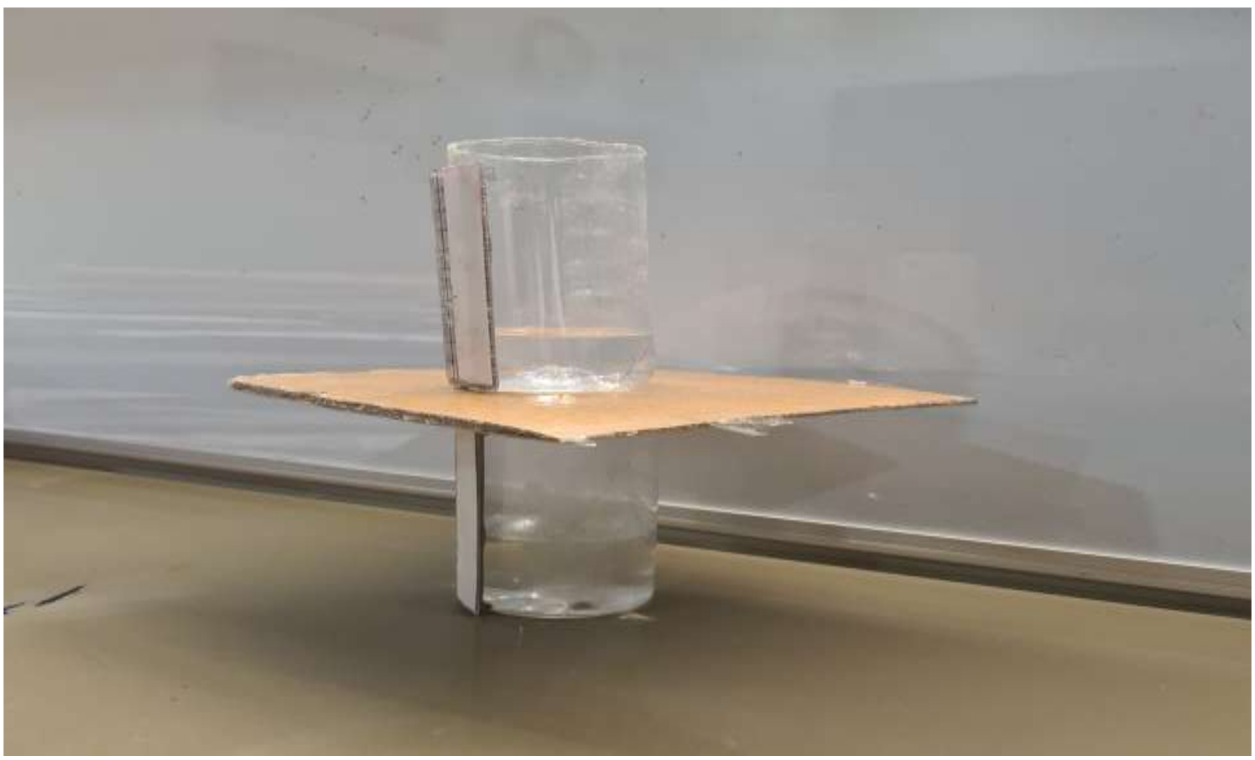
1 small needle to make a hole
2 wire gauge to measure the radius of the needle
3 two empty water bottles of cylindrical shape
4 A stopwatch to record the time
5 a square cardboard for the bottle to rest on, with a hole in the middle for the water to flow from one bottle to another.
6 tape
7 two scales
8 double sided tape

Procedure:

1 An orifice was created at the bottom of one bottle and the diameter of the needle was measured using a wire gauge.
2 the orifice was covered with tape.
3 a double sided tape was used to stick scales on the water bottle.
4 water was poured upto 9 cm in the bottle with the hole and it was placed on top of the cardboard which was then placed on top of the other bottle.
5 The tape was pulled away and water was allowed to flow from one bottle to another
6 The change in height and time was recorded.
Radius of needle=0.915mm
Radius of water bottle=2.5cm or 25mm
Initial height upto which water is filled=9cm

Here is a picture of my water clock:





Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	803
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1004

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	797
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	201
4	1.25	400
5	0.625	800
6	0.5	1001

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	996

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800

6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	48
2	5	97
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	51
2	5	102
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	Change in height(cm)	Time (seconds)
1	10	50
2	5	100

3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	**Change in height(cm)**	**Time (seconds)**
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

Serial Number	**Change in height(cm)**	**Time (seconds)**
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

The following table gives the average values:

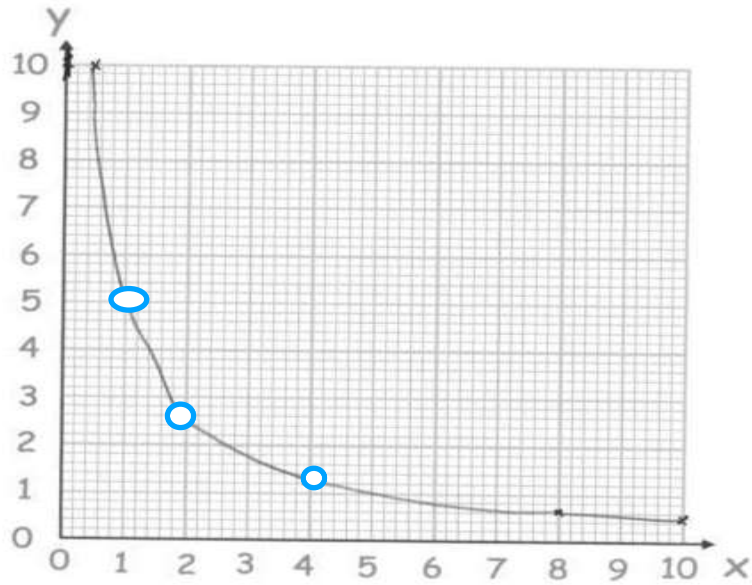
Serial Number	**Change in height(cm)**	**Time (seconds)**
1	10	50
2	5	100
3	2.5	200
4	1.25	400
5	0.625	800
6	0.5	1000

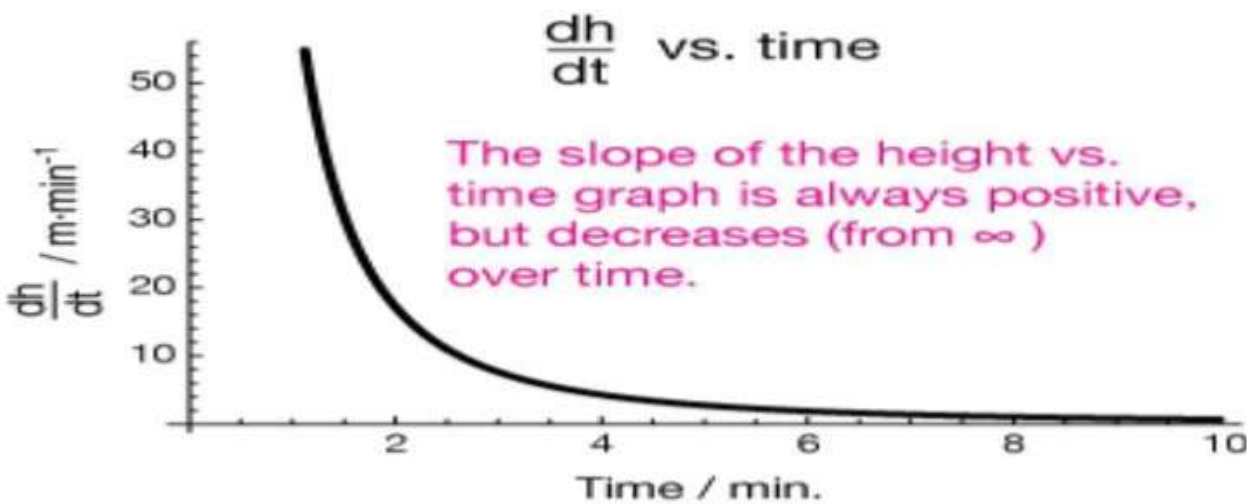
The graph of change in height with respect to time

Scale:
X axis-
1cm=100 seconds :
Change
In height(Y axis)

time

Change in height versus time graph according to Torricelli's law should look like the following:
Slope is always positive but decreases over time





Conclusion:-

The following project involved building a water clock, collecting experimental data for the change in height with respect to time and plotting the graph. Before starting working on this project with Professor Norman Lowney my understanding of calculus was not upto the level at which it needed to be. Along with working on the water clock I started studying for the AP calculus BC exam which enhanced my understanding of calculus and its applications. The project required me to get a brief understanding of the background of the water clock and its historical significance.

I also read and understood the work done by famous mathematician/physicist Evangelista Torricelli and his law establishing the rate of flow of water under the influence of gravity. Building the water clock and collecting materials was a huge challenge with all restrictions and safety measures to be followed during the pandemic. After building the water clock, I took different readings and measurements for the change in height with respect to time and then plotted a graph for the same.

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