PHYSICS THROUGH TIME: DESIGNING A WATER CLOCK THAT CAN ACCURATELY TELL TIME

Sumaiya Sathar

ABSTRACT: Throughout history Muslim civilization has contributed immensely towards so many aspects of life, from the discovery of coffee to the development of sophisticated technology. They have invented time measuring devices, irrigation machines, and entertainment devices, and made many important discoveries in the fields of science, astronomy, medicine, mathematics, geography, architecture, and more. Unfortunately, the contributions of non-European cultures, including those of Muslim inventors, are often overlooked and instead educational institutions tend to focus on the discoveries of European scientists, even if research by Muslim scientists is at the root of many of those discoveries.

This paper aims to highlight some of the contributions of Muslim scientists, specifically in the field of physics where Muslim inventors were well known for the development of various sophisticated time keeping devices. To gain a better understanding of the underlying physics behind water clocks, a literature review was conducted primarily on papers published by the Institute for Science and Technology in Islam and by the Royal Society of London.

The papers investigated the mechanism of the Fez clock, as well as the best vessel shape and hole diameters for the simplest clepsydras. Findings from the papers suggest that the best vessel shape for a clepsydra is a quartic vessel with a 0.5-1.0mm diameter hole and that a float system was present within the Fez clock. It is unknown whether the Fez clock had a quartic vessel in its design, but it is worth noting these findings as the earliest scientists may have conducted such experiments themselves and used the data collected to design the astounding clocks we see now.

Introduction

Although time-telling has been important to many nations and cultures, it was not until the emergence of Islam that its technology and sophistication was given an enormous boost. Islam is a religion that recognizes the significance of time and appreciates its seriousness. The prophet Muhammad, peace be upon him, taught Muslims that time is a blessing that must be valued and used wisely. There is even a chapter titled “The Time” in the Quran, the holy book which Muslims adhere to, which emphasizes the importance of time and encourages Muslims to both reflect on the passage of time and use time to do good.

The lives of Muslims are structured around the five daily prayers, each of which must be prayed during a specific time of the day. Fajr is prayed at dawn, Dhuhr at midday, Asr in the mid-afternoon, Maghrib at dusk, and Isha at night. During the month of Ramadan, Muslims must again watch the time closely so they can start their fast at dawn and break their fast at dusk. It is no surprise then that time-keeping devices were of the utmost importance amongst Muslims. Of the many time keeping devices developed, water clocks are one of the earliest devices in the history of mankind. There are several examples of time-keeping devices from the Muslim world, including Caliph Harun al-Rashid’s clock that he gifted to Charlemagne and Ibn Al-Haytham’s novel water clock, to name a few.

The use of the water clock can be tracked all the way back to ancient times. The very first water clock was just a simple vase with a hole, known as clepsydra, and was found in ancient Egypt. It consisted of a vessel with a small hole at the bottom. The vessel was filled with water to a fixed mark, then allowed to drain. This allowed a constant interval of time to be marked out. Another type of clepsydra was a perforated bowl placed upon water, and it was considered to take a constant time to fill up and sink.

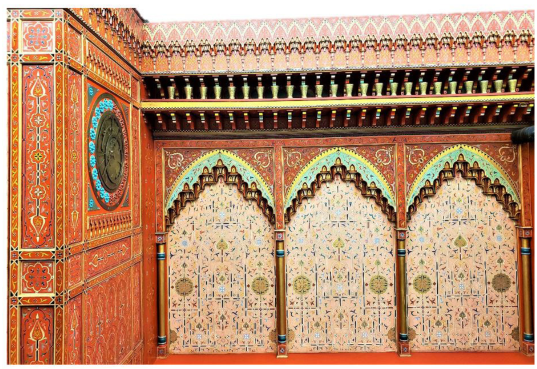
This figure shows the oldest specimen of a clepsydra to have survived in a well enough condition to be fully reconstructed. It was excavated at Karnak in Upper Egypt and is dated to about 1400 B.C. Reproduced from Mills A. A. (1982) Newton's water clocks and the fluid mechanics of clepsydrae. Notes *Rec. R. Soc. Lond*. 37(1) 35-61 http://doi.org/10.1098/rsnr.1982.0004 with permission of The Royal Society

After the development of the clepsydra, we find many models of water clocks around the world, especially in Muslim countries where time measuring devices are central in society. One can see examples of these clocks in Mosques from Baghdad to Damascus to even Morocco. These water clocks were a combination of engineering and artwork and used very complex mechanisms, some of which were forgotten over time and were not very well known.

The clocks were especially useful during the night when sundials could no longer be used. The Al-Lija'i clepsydra clock, located within the minaret of the Al-Qarawiyyin mosque in Fez, Morocco, is the oldest extant water clock known and was built by the muwwaqqit (a title given to the astronomer who oversaw the calculation of prayer times) of the Qarawiyyin Mosque back in the 1300s, Abu Zayd Abdurrahman bin Sulayman Al-Leja'I.

Literature Review

The Fez clock divides the day into 24 hours. The dial is divided into four minutes each. Water inflow was calculated so that it remained uniform every second of the day. Within the clock there is a sinking float and two carriages. The first carriage holds small brass balls, and the second holds larger brass balls. The sinking float causes a minute pointer on the dial to move every four minutes. The movement of the minute hand causes one small ball to fall into the corresponding brass bowl (out of the 24 total bowls), making a ringing sound, and the movement of the hour hand results in the dropping of a larger brass ball, which makes a larger ringing sound (Institute for the History of Arabic-Islamic Science).

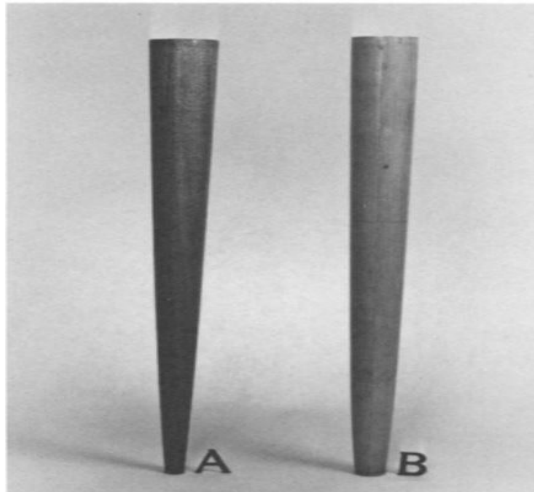


Model of Al-Lija'i clepsydra clock located in the room of Al-Muwaqqit in the Al- Qarawiyyin mosque in Fez, Morocco. This is the oldest extant water clock known. It was used by Muslims to determine prayer times and dawn/dusk for days fasting. The clock is currently being studied and restored to working condition. - Source: Moroccan water clock model, Istanbul Museum of the History of Science and Technology in Islam, Istanbul, Turkey (own photo).

In addition to the sound of the brass balls falling, one of the 24 wooden doors behind the bowls closes, which gives an overview of the hours elapsed and can be viewed from afar. Then the carriage moves to the next brass bowl and the pattern continues. There are two types of water clocks: clocks that depend on inflow of water and clocks that depend on outflow. Both the clepsydra and the clock in Fez depend on outflow of water. The volume of water dictates the sinking of the float to which all these other components are attached, but the clock has been designed in a way that the two carriages move opposite to the direction of the sinking float, even though they are connected by a pulley-like system (Institute for the History of Arabic-Islamic Science).

Methods

Water clocks depend on physical properties to function, such as buoyancy, pressure, angular velocity, viscosity, and flow rates (Al-Hassani). I was interested in learning more about the Fez clock and the mechanism behind it. In my research, I came across a study published by a group of scientists who determined what vessel shape, hole diameter and capillary size would



This figure shows the shapes of the vessels used in the experiment. Figure A is a parabolic vessel and figure B is a quartic vessel. Reproduced from Mills A. A. (1982) Newton's water clocks and the fluid mechanics of clepsydrae. *Notes Rec. R. Soc. Lond.*37(1) 35-61 http://doi.org/10.1098/rsnr.1982.0004 with permission of The Royal Society

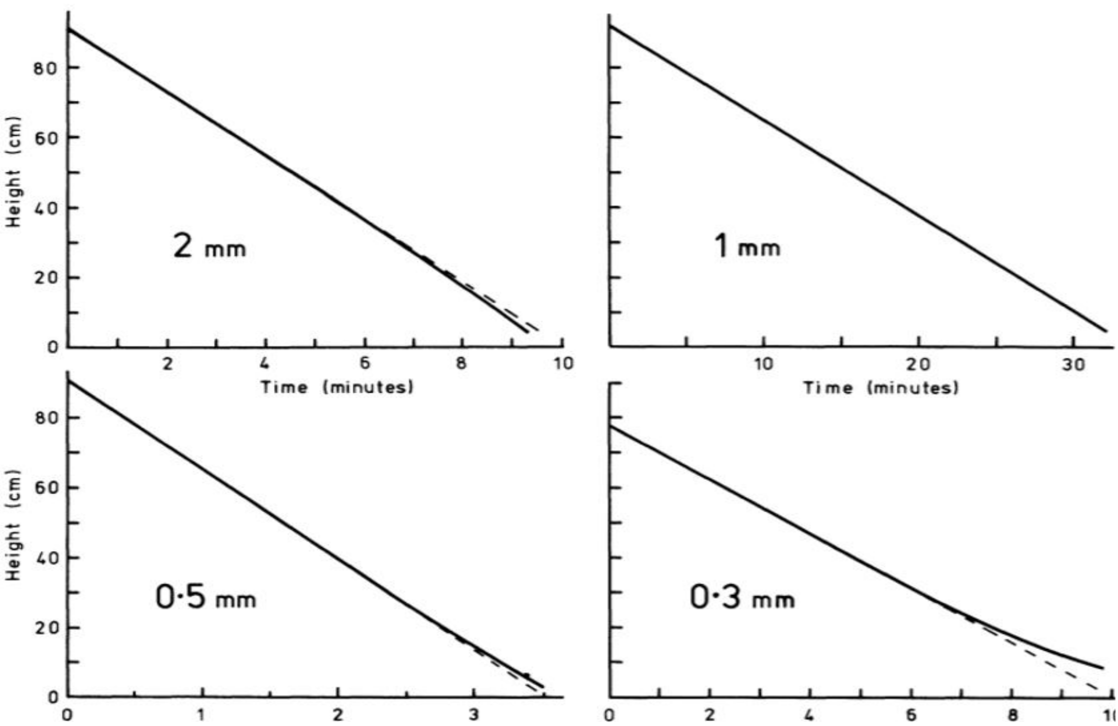


Figure 1 - These graphs show the rate of fall of water-level with time in a quartic vessel draining through holes of the indicated diameters. The solid line is the rate of water flow based on the data collected, and the dotted line is the ideal linear graph should the water flow consistently. We can see that these graphs are quite linear, which means that the water tended to flow at a consistent rate. The most linear is the vessel with an aperture of 1mm, and the one that was the least consistent is the 0.3mm. Reproduced from Mills A. A. (1982) Newton's water clocks and the fluid mechanics of clepsydrae. *Notes Rec. R. Soc. Lond.*37(1) 35-61 http://doi.org/10.1098/rsnr.1982.0004 with permission of The Royal Society

result in consistent flow based on their research of the clepsydra. Translucent fiberglass was molded to make two long, narrow vessels, one with a more quartic shape and the other more paraboloidal. Apertures were made by drilling 0.30, 0.50, 1.0, 2.0 and 3.0mm diameter holes in 0.1mm thick brass foil. The capillaries were made of 100mm glass precision tubing, with holes of diameter 0.5, 1.0, 1.2, 2.0 and 3.0mm. Tests were conducted using room temperature water to maintain constant viscosity (Mills).

The vessel was supported vertically, and the end was taped. Water was then poured in and some time was given for the water to stop bubbling and to settle. Afterwards, the adhesive tape was removed. At certain times on the stopwatch, the position of the meniscus of the water was marked on the tube until the vessel was empty. After that, the height of each mark was measured and plotted on a graph (Mills).

Results

After collecting the data, the scientists went on to graph their results based on the height of the meniscus over time. They then used these results to determine which graph looked the most linear, indicating a more consistent rate of water flow. The first figure is of the quartic vessel that used apertures of different diameters. The quartic vessel graphs were quite linear, particularly the vessel with the 1mm hole (Mills).

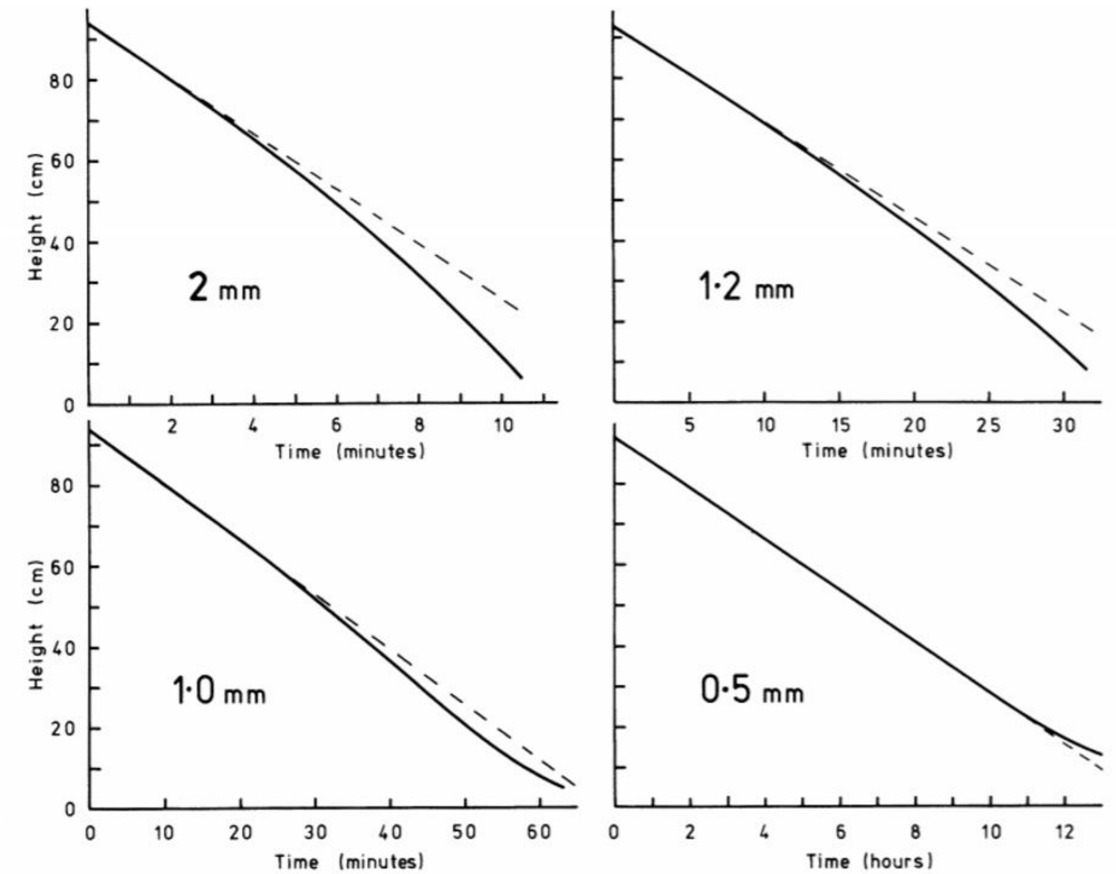


Figure 2 - This figure depicts graphs that show the rate of fall of water-level with time in a paraboloidal vessel draining through capillaries of the indicated internal diameters. Compared to the quartic vessel, the paraboloidal vessel is much more inconsistent with the rate of water flow. Of these four capillary diameters, the most linear was the smallest diameter, which was 0.5mm. As the diameter of the capillary increases, so does the inconsistency of the waterflow, so smaller is better. Reproduced from Mills A. A. (1982) Newton's water clocks and the fluid mechanics of clepsydrae. *Notes Rec. R. Soc. Lond.*37(1) 35-61 http://doi.org/10.1098/rsnr.1982.0004 with permission of The Royal Society

The second figure is of the data plots for the rate of water-level with time from paraboloid vessels that used capillaries for the water to pass through. Compared to the quartic vessel, the paraboloid vessel graphs were not as linear, indicating that the rate of flow was not as consistent, especially as the volume decreased. Out of the four capillary diameters tested, 0.5mm gave the most linear graph (Mills).

Conclusion

Based on experimentation we know that between a quartic and paraboloid vessel, a quartic vessel was better for controlling water output. In addition, by comparing the graphs, scientists were able to determine that, of the different diameters tested, the 0.5-1.0mm diameter turned out to be the best width for constant water flow. It raises questions as to what vessel shape was primarily used in the creation of water clocks such as the clock found in Fez.

Additionally, the history of the water clock and other scientific advances highlights the importance of studying the contributions of Muslim scientists and inventors from non-European countries. Many of the important inventions and discoveries made by Muslim scientists are often overlooked and those scientists are not properly acknowledged. Not only will studying such contributions bring new perspectives, awareness, and a greater appreciation of their amazing contributions, but it will also bring to light a part of our history that is often overlooked and help fill in the hole in our understanding of the past.

Without the contributions of Muslim scientists, we would not have acquired the knowledge we have today at such a fast rate, and it is time we acknowledge all the inventors that have shaped the world as we know it today and study their contributions in all fields of study.

Acknowledgements

Thank you to Jay Howard for guiding me in my research, and thanks to Alyssa Berger for her assistance with acquiring permissions for all the images used in this paper. Additionally, I would like to thank the team at CROW for their consideration and helpful feedback.

References

Al-Hassani, Salim. “Al-Jazari’s Castle Water Clock: Analysis of Its Components and Functioning.” *Muslim Heritage*, 13 Mar. 2008.

Institute for the History of Arabic-Islamic Science. “Science and Technology in Islam.” *Frankfurt am Main, Institut fü Geschichte der Arabisch-Islamischen Wissenschaften an der Johann Wolfgang Goethe-Universität,* 2010.

Mills, A. A. “Newton’s Water Clocks and the Fluid Mechanics of Clepsydrae.” *Notes and Records of the Royal Society of London*, vol. 37, no. 1, 1982, pp. 35–61.