A Hands-on Experimentation and Educational Study for a 2000 years-old Puzzle, the Mpemba Effect

Dimitrios Gousopoulos, Sarantos Oikonomidis & George Kalkanis
University of Athens, Pedagogical Department P.E.,
Science, Technology and Environment Laboratory
13a Navarinou St, Athens GR-106 80
dimgouso@gmail.com, sarecon@gmail.com, kalkanis@primedu.uoa.gr,
http://micro-kosmos.uoa.gr

Abstract. *In this paper we study Mpemba Effect, where initially hot water, freezes faster than initially cold water, under specific conditions. This effect is a 2000 years-old puzzle. In order to investigate this unusual phenomenon experimentally, we first had to study all recent theories which have been developed to explain it. After that, we designed an experimental procedure in an appropriate way, so as to study some parameters' influence to Mpemba's Effect appearance. Our study leads us to some interesting conclusions that are incorporated in this paper. Furthermore, in the last part of this paper we propose an educational approach to Mpemba's Effect.*

Keywords. Mpemba's Effect, Evaporation, Convection Currents, Environmental Influence, Gas Content, Supercooling, Scientific / Educational by inquiry model.

1. Introduction

The purpose of this paper was to study the experimental parameters which mostly affect Mpemba's Effect appearance and contribute experimental data to the international bibliography. Moreover, we used Mpemba Effect in order to give an alternative approach to the "heat transfer" teaching at the Greek secondary education.

The Mpemba's Effect was well known in the previous centuries. A characteristic example is that in 350 BC Aristotle wrote:

"If water has been previously heated, this contributes to the rapidity with which it freezes" (Meteorologica)

Aristotle used this observation in order to support his theory called "antiperistasis", according to which there is a sudden increase in the intensity of a quality as a result of being surrounded by its contrary quality.

In the 15th century Clagett described Giovanni Marliani's experiments. More specifically he wrote the following:

"...In order to support his contention that heated water freezes more rapidly, Marliani first points to a passage in Aristotle's Meteorologica affirming it. However, does not depend on Aristotle'sstatement alone. He claims that not only has he often tested its truth during a very cold winter night, but that anyone may do so.

Moreover in 17th century both Francis Bacon and Descartes did experiments in order to confirm or reject Mpemba's Effect.

In the "Novum Organum" Francis Bacon wrote:

"...water a little warmed is more easily frozen than that which is quite cold..."

Descartes wrote in his famous book called "Les Meteores":

"...And we can also see by experiment that water which has been kept hot for a long time freezes faster than any other sort...."

From all the above historical statements, we can see that Mpemba's Effect was well known in the past, and many famous scientists and philosophers have study this strange phenomenon.

Mpemba's Effect was reintroduced by a secondary school student Mpemba in 1963 in Tanzania. Mpemba and professor Obsorne (professor from a local university) undertook several experiments in order to test the effect and published their results.

After this publication, it had been revealed that this phenomenon was well known in the food-freezing industry and for the ice cream makers.

Recently, new theories have been developed which try to explain Mpemba's Effect. So, according to the previous mentioned theories the parameters that possibly lead to Mpemba's Effect appearance are the following:

Dimitrios Gousopoulos, Sarantos Oikonomidis & George Kalkanis (2010). A Hands-on Experimentation and Educational Study for a 2000 years-old Puzzle, the Mpemba EffectM. Kalogiannakis, D. Stavrou & P. Michaelidis (Eds.) *Proceedings of the 7th International Conference on Hands-on Science.* 25-31 July 2010, Rethymno-Crete, pp. 377 – 381
http://www.clab.edc.uoc.gr/HSci2010

- Evaporation: Suppose that we have two bodies of water. The initial temperatures for the hot and cold water are 70°C and 30°C respectively. Our goal is to measure the time in which cold and hot water reach 0^0C and examine if Mpemba's Effect appears. A parameter that might change during the experiment is the **mass of water**. Both bodies of water initially have the same mass. But if the initially hotter water loses mass due to evaporation, then the 70°C water cooled to 30°C will be easier to freeze. In other words, due to the fact that initially hotter water loses mass, less energy will need to be removed in order to freeze it. This is one of strongest theoretical explanations for the Mpemba Effect.

- Convection Currents: Another parameter is the **temperature distribution of the water**. As the water cools convection currents are developed and the temperature becomes non-uniform. Suppose that we study the previous mentioned experiment. When the initially hotter water has cooled to an average temperature of 30°C the top of the water will be hotter than 30°C, whereas the bottom of the water will be cooler than 30°C. This non-uniform temperature distribution with an average temperature of 30°C will lose energy faster than uniformly 30°C water. Convection Currents are extremely influenced by container shape, as a results this factor to have different impact to different containers. Moreover, "Convection Currents" parameter can easily be combined with "Evaporation" parameter in order to lead to Mpemba's Effect appearance.

- Environmental Influence: Another important factor for Mpemba's Effect appearance is Environmental Influence. The initially hotter water can change his surrounding environment in such way so as to affect the rate of cooling. In details, suppose that the containers are sitting on layers of frost. Hot water causes the layer of frost to melt, establishing better thermal conduct. This means that initially hotter water cools faster than the initially cooler water.

- Gas Content: Generally hot water contains less dissolved gas than cold water. Gas Content affects water properties. Based on this factor many theories have been developed until today, but none of them can be proved experimentally

- Supercooling: Is the process of lowering the temperature of a liquid or a gas below its freezing point, without becoming a solid. Many experiments have been developed in order to reveal supercooling affect to Mpemba's Effect appearance. Unfortunately, none of them have shown clearly in which way supercooling is significant for Mpemba's Effect.

2. The experimentation

Based on the previous mentioned theories, we designed an appropriate experimental procedure. In details:As a mean of cooling we used a rock salt and ice bath, we measured a chosen volume of water into a pyrex beaker and we used two thermometers and one stopwatch.

We chose 4 different experiments in order to study Mpemba Effect:

i) 50mL water - pyrex beaker

ii) 50mL water with a layer of oil on top of the water-pyrex baker

iii) 100mL water-pyrex beaker

iv) 100mL water with a layer of oil on top of the water- pyrex beaker

Furthermore, we chose 5 or more initial temperatures to test Mpemba Effect and followed the same procedure for each initial temperature:

Firstly, we heated the water to the desired initial temperature, we measured the chosen volume of water into a pyrex beaker and then quickly weighed the beaker and placed it in the rock salt and ice bath. During the procedure we had been recording water's temperature per minute, till it reaches 0^0C. We should underline that we have chosen to measure the time until water reaches 0^0C, since we did not want to involve supercooling in our experiment. Moreover, we should mention that we used oil layer on top of the water so as to reduce evaporation.

The experimental procedure

3. Data Analysis

For each initial temperature we plot the temperature-time graph. Then we created a diagram of temperature differences for each minute. Finally, based on the previous diagram we divided the graph into 2 or 3 parts and we used Logger Pro III software, in order to determine the average rate of temperature for each part.
For instance, at the initial temperature of 22.5°C (50mL water-pyrex beaker) we have the following graphs and diagram:

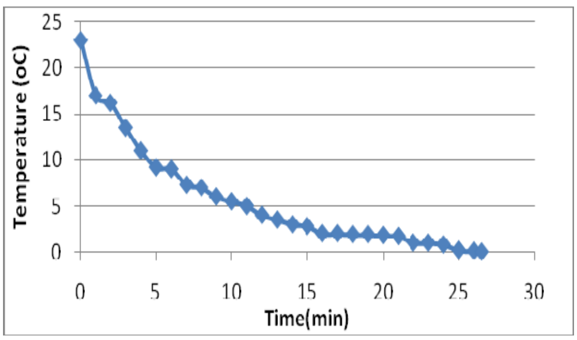


Figure 1

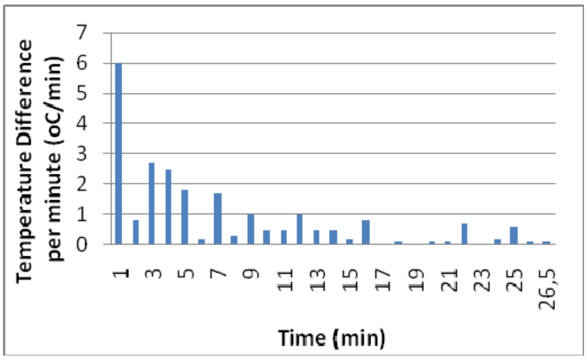
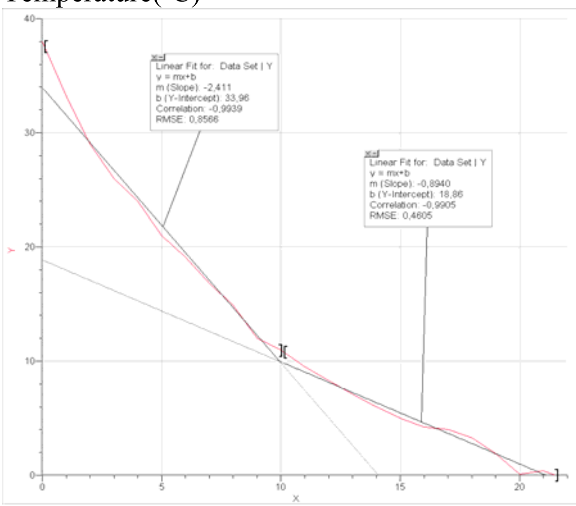


Figure 2

Temperature(^{0}C)



Time (min)

Figure 3

Moreover, at the initial temperature of 38°C (50mL water-pyrex beaker) we have the following graphs and diagram:

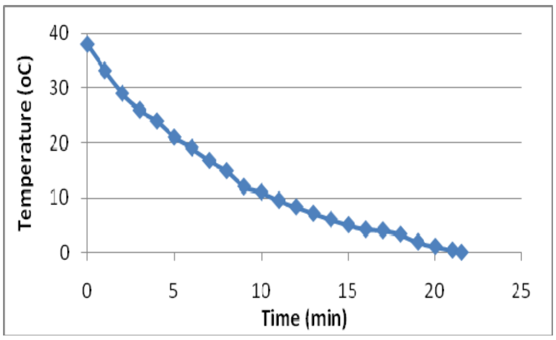


Figure 4

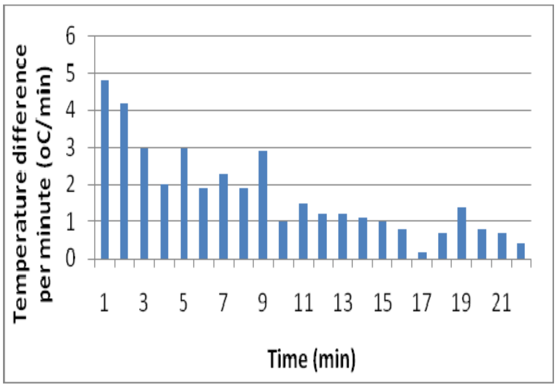
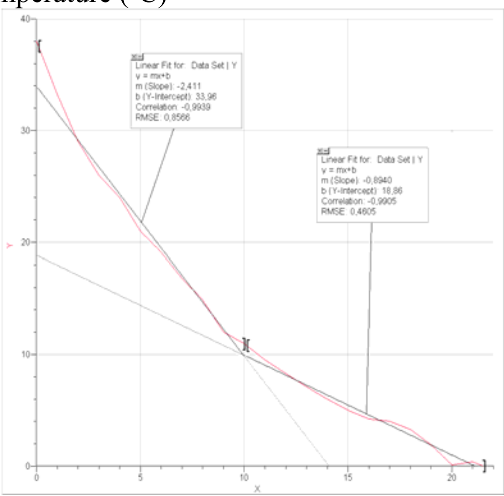


Figure 5

Temperature (^{0}C)



Time (min)

Figure 6

Based on the previous graphs and diagrams we can see that at the 10th minute, the temperature in the 1st case was 5.5^{o}C and in the 2nd case was 11^{o}C > 5.5^{o}C. However, figures 3 and 6 show us that at the same minute the rate of temperature change was 0.314^{O}C/min in first case (initial temperature: 22.5^{o}C), whereas in the second case (initial temperature: 38^{O}C) the rate of temperature change was 0.9^{O}C/min >> 0.314^{o}C/min. So, the body of water in the second case, despite the fact that at 10th minute has 2-time higher temperature, comparing to the first case, it reached 0^{0}C first, since it was characterized by 3-times higher rate of temperature change at the same minute.

The previous mentioned data analysis methodology was applied to the remained initial temperatures in all four types of experiment.

4. Conclusion

After analyzing experimental measurements, we construct the graph in Figure 7. The x-axis shows the initial temperature of the water. The y –axis shows the time it took for the water to reach 0^{0}C

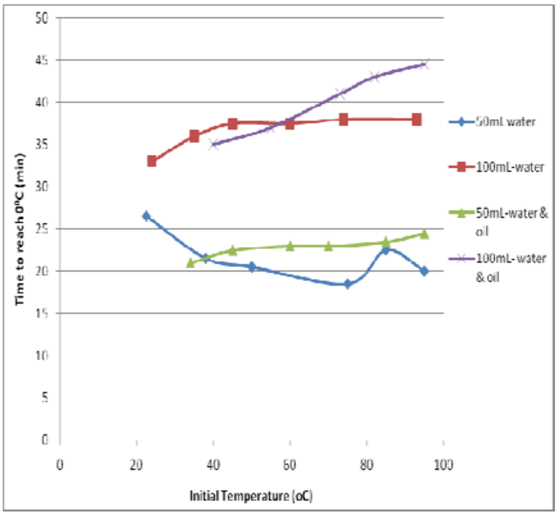


Figure 7

Based on the previous graph, we conclude that in the 1st experiment (50mL water in pyrex beaker) samples that were initially hotter reached 0^{o}C faster than samples that were initially cooler, confirming Mpemba's effect. In the 2nd experiment, where the only difference was the oil-layer on the top of the water, Mpemba's Effect has not been confirmed, showing how important evaporation is in order Mpemba's Effect to occur. 3rd and 4th experiments did not confirm the phenomenon we examine. Although, there have been stated many interpretations on Mpemba's Effect, there has not been developed any mathematical equation so as to describe time evolution of the temperature, such as Newton law of cooling. So, using our experimental measurements, we intent to give a quantitative approach to the effect we study.

Finally, we can use this unusual phenomenon in order to give an alternative approach to "heat transfer" teaching at secondary education. In details, we created appropriate worksheets which are based on the "scientific / educational by inquiry model". The 5-steps which characterise our worksheets are the following:

1. Trigger of Interest

2. Hypothesizing expression

3. Experimenting- testing the hypothesis

4. Concluding

5. Application

Mpemba's Effect introduction to "heat transfer" teaching constitute an enriching activity of Greek secondary education curriculum.

4. References

[1] Monwhea Jeng, "Hot water can freeze faster than cold?"arXiv:physics/0512262v1 29 Dec 2005

[2] G.S Kell "The freezing of hot and cold water" Am. J. Phys 37 (5). 564-565(1969)

[4] Network of Educational Innovation http://schoolnet.protovoulia.org/

[5] Tsagliotis, N. (2005). Hands-on science activities for the teaching and learning of mechanical energy with 6th grade primary school children in Greece. In the Proceedings of the 2nd International Conference on "Hands-on Science: Science in a changing education", 13-16 July, Rethymno, University of Crete [Project "Hands-on Science" No: 110157-CP-1-2003-1-PT-COMENIUS-C3].

[3] J. van der Elsken, J. Dings, and J. C. F. Michielsen, "The freezing of supercooled water," J. Mol. Structure 250, 245-251 (1991)

[4] M. Freeman, "Cooler Still—An Answer?," Phys. Educ. 14, 417-421 (1979).

[5] Kalkanis G "Educational Technology" University of Athens 2002

[6] Kalkanis G "Educational Physics" University of Athens 2002

[7] Science & Engineering Indicators 2008, Elementary and Secondary Education Chapter1, 2008

[8] Investigating the Mpemba Effect: Can Hot Water Freeze Faster than Cold Water?, http://www.sciencebuddies.org/science-fair-projects

[9] Does hot water freeze first? http://www.physicsworld.com

[6] Tsagliotis, N. (2005). Approaching conceptual change in the teaching and learning of mechanical and solar energy with 6th grade primary school children in Greece. In Fischer, H.E. (Ed.) Developing Standards in Research on Science Education, London: Taylor & Francis, pages 221-22