International Baccalaureate Chemistry Extended Essay

TED Ankara Collage Foundation High School

"Investigating the effectiveness of galvanizing in metals that are used in water tanks with respect to their hardness, by performing corrosion with usage of water vapor"

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ABSTRACT

Water is essential for life. It is not coincidence that the first living organisms generated in water or that we can live for weeks without eating but only maximum one week without drinking. These are researched by scientists and found out that enzymes need water to be activated and that's why water composes big parts of bodies of living organisms. As not all cities are constructed near seaside, the carriage of water problem arouses. It becomes such a problem that it can be the determining factor for electing the mayor.

I started my extended essay from questioning the difficult organization of distributing and storing water in big cities. The lack of raining makes the storage important. Therefore, I focused on storage of water and found out that there are several ways of building water reservoirs and there is a big difference in costs. The most popular two were those made of stainless steel and those that are galvanized. As galvanized ones are cheaper, I asked the question **if galvanization is effective enough to build durable water reservoirs.** I developed my own method and compared a galvanized metal to a non-galvanized metal and see the durability that galvanization adds to a metal. In my experiment I recorded mass values in order to calculate the rate of corrosion. My experiment showed me that although the non-galvanized metals had increasing graphs of mass, the galvanized metals' masses didn't change.

In the end, I concluded that galvanization is effective enough to build durable water reservoirs. Having the high cost of stainless steel and the durability that galvanization adds to metals, galvanization could be the most effective method for many societies especially in economical crisis time.

INTRODUCTION

Water is essential for life and it is one of the main requirements for both human beings and other living organisms since the beginning of life. Between 55-78% of the human body size depends on water, in addition, for example in average 75% percent of chickens and 70% of elephants consists of water[1]. It is not that the enzymes in all living organisms need water to be activated but water is also used in agriculture, chemistry, and also for drinking as it also has minerals in it, hygiene and extinguishing fires. These are just a few main topics of all that water is used for. It is stated by scientists that a person can live without eating for weeks but the overall maximum time that a person can endure without drinking water is one week and it is just 3-4 days for many people[2]. Besides, scientists' searching for water in other planets in order to find clues of living organisms shows the importance of water in living organisms' life.

In history, settling near to natural water resources had been a big advantage for societies. However, today, with 6.8 billion world population[3], it is impossible for every person to live close to natural water resource. Therefore, carrying and storing water problems arise. It is not the problem of investing for carriage and storage of water but you also need to take care of these in such a way that the pipes and water reservoirs should also be healthy for water and also durable. From this point the industry of water pipes and water reservoirs arise.

[1] Krough, David. Biology, A guide to the natural world
[2] Krough, David. Biology, A guide to the natural world
[3] World Population <http://en.wikipedia.org/wiki/World_population>

Since the climate changes may occur and the amount of rain cannot be predicted exactly, water reservoirs are so important especially in summer months. A similar incident occurred in Ankara, the city that I live in which was the departure point for me to choose this topic for my extended essay. The same year, the city with the highest population in my country, Istanbul, also had the same problem. The amount of rain was so low that there was lack of water and the municipalities in both cities started to give water in certain hours of a day. That resulted in serious protests against the mayors and the mayors had to invest for new waterways from further water resources.

During those times, people living in apartments that have water reservoirs were advantageous. They didn’t get affected from the decision of the municipalities. They stored the water in those certain hours and used it when they wished.

It was the discovery of the water reservoirs for me as I hadn’t thought about water pipes or water reservoirs before. I started to find out the difficulty of creating such systems in every city with having the idea of how it is necessary in my mind. The water reservoirs drew my attraction as they were advantages for many of my friends. I researched for water reservoirs’ construction costs and discovered a new business sector. There were 2 main water reservoir types that are widely used: ones produced from stainless steel and those produced from metals and galvanized after produced. The reason of widely usage of these two types is their durability.

The durability of a water reservoir is not just its durability for impacts from outside but also its durability to rusting. Rusting is oxidation of metal with the effect of water. From these two widely used water reservoirs, one produced from stainless steel is expensive as stainless steel is an expensive raw material. However, ones that are galvanized are relatively cheaper, so their usage is wider. As the stainless steel is limited on earth and much more expensive, I wondered if galvanized metals are durable enough. My aim in this essay is to research the advantages and disadvantages of galvanizing in many aspects with finding out ***if galvanization is effective to produce a durable water reservoir. I presume that, galvanization is an effective method; therefore water reservoirs produced from metals and galvanized are the most effective related to their costs and durability.***

Picture – 1: A picture of a piece of stainless steel

Picture – 2: A picture of a piece of galvanized metal from my experiment

PLANNING AND DEVELOPMENT

My research question is about the effectiveness of galvanizing. Effectiveness consists of two things: cheapness and durability. Galvanizing is cheap so the question is how durable it is? To find out the durability of it I thought that I should find an experiment that I can compare the durability of a galvanized metal to that of a metal that is not galvanized. However, all conditions except being galvanized must be same for both metals in order to find out the exact result of galvanization. At this point, the procedures that a metal undergo before being galvanized became a problem. Those procedures were putting metal inside trichloro ethylene and hydrochloric acid with high molarity respectively. The purposes of these procedures are to cleanse the layers on the metal such as oil layer to make galvanization more effective. Thus, I decided to carry out the same procedures with the metal that is not galvanized.

Picture – 3: The procedure of putting the metal in trichloro ethylene

Therefore the beginning of my experiment was putting the metal that is not galvanized into trichloro ethylene and hydrochloric acid. The molarity of the hydrochloric acid should have been high therefore I used 18 M hydrochloric acid. To put the metal in those two liquids, I tied it with a copper wire. I was careful with the wires that both galvanized and non-galvanized metals were tied with the same length of and therefore same massed wires. At first, I put the metal in the trichloro ethylene for 6 times and for 6 seconds each time. I moved the metal in the trichloro ethylene to make sure that every part of the metal is covered. After that, I kept the metal in the air for about 30 seconds that the trichloro ethylene left on the metal vaporized. Right after, I put the metal in the 18 M hydrochloric acid and waited for 3 minutes. During that procedure, I observed a green colored liquid which I think is the result of the reaction that took place. After those 3 minutes, the conditions of the metals except being galvanized were all same.

The corrosion of a metal is the involvement of oxygen in the metal that comes from the water. An example of that with iron is:

$$2Fe + 0_2 + 2H_20 \Rightarrow 2Fe\ (OH)_2$$

That’s why when rust occurs, the mass of the metal increases as the mass of the oxygen should be added to the metal’s mass. Therefore observing the difference in a metal’s mass can reflect the rate of corrosion of the metal. Thus I had mass recordings of the metals in my experiment and will draw a conclusion from those recordings. In addition, instead of water I used water vapor which shows the same properties and causes the corrosion in order to hold the oxygen that is involved in the metal on the metal and observe the change of mass accurately. Therefore I placed two water vapor producing machines and the metals right in front of them.

Picture – 4: The two water vapor producing machines and the two metals right in front of them.

However, after setting up the system, I became suspicious. The ventilation had to work as the trichloro ethylene and hydrochloric acid exported their odors. The movement of the air in the laboratory was so fast. As the amount of mass change is so low, I thought that the movement of air could cause the falling of the rusted metal in the floor or inaccuracy in the measurement of the mass by the weight. Thus, I decided to set up my experiment in the space between the two experiments where there is no ventilator.

Picture – 5: The improved setup of my experiment.

Everything looked great but there was another problem that aroused in my mind. I observed water droplets on the metals when I stopped the water vapor producing machines in order to record the metals' masses. That meant that the mass that I would record included the mass of the droplets. Therefore, I had to find a solution which would remove the droplets that the weight would only show the masses of metal and the oxygen involved in the metal. Thus, I poured acetone on the metals to cause the vaporization of the water droplets. Before every measurement, I cleaned each metal with acetone.

As the system was set up, I could start my experiment. In my experiment, the constant variables were going to be the temperature, the pressure, the amount of water vapor that both metals receive. To keep the temperature and the pressure constant, I conducted my experiment in a small room that has no ventilator and I kept the doors closed. In addition, I measured the temperature and the pressure in the room at every 2 hours to make sure that the temperature and the pressure are constant. In addition, I set the both water vapor producing machines at the same rate of producing water vapor and placed the metals at the same distances from the water vapor producing machines to keep the water vapor received by the metals constant. My independent variable was time and my dependent variable was the increase in mass for each metal. I did 5 trials of the experiment in order to get accurate data collection and reach an accurate conclusion with that data. I recorded the masses of both metals every 2 hours.

SETUP AND METHOD

Materials:

2 Liters of 18 M Hydrochloric Acid

2 Liters of Trichloro Ethylene

2 Water vapor producing machines

1 Piece of galvanized metal (Dimensions: 13cm length, 10cm width)

1 Piece of non-galvanized metal (Dimensions: 13cm length, 10cm width)

2 Copper wires of almost same masses and around 4500 g

1 Electronic Scale with an uncertainty of 0.001 g

2 Liters of Acetone

2 Stands

1 Thermometer

1 Barometer

Method:

1. Both use the thermometer and barometer and record the values of temperature of and pressure in the room.

2. Cut two equal lengths of copper wires. Measure and record their masses. Then, tie both pieces of metals (galvanized and non-galvanized) with the copper wires.

3. Wear gloves and mask for the trichloro ethylene and hydrochloric acid procedures.

4. Pour trichloro ethylene in a case that you can put the metal in trichloro ethylene and make sure that every part of the metal could be exposed to trichloro ethylene in that case.

5. Pour hydrochloric acid in another case that you can put the metal in hydrochloric acid and make sure that every part of the metal could be exposed to hydrochloric acid in that case.

6. The states of galvanized and non-galvanized metals are different. To make the conditions equal, we should first do the trichloro ethylene and hydrochloric acid procedures for non-galvanized metal and by this way cleanse the layers such as oil layer on the metal. So, put the non-galvanized metal in the trichloro ethylene for 6 times that each time it stays inside for 6 seconds. Move the metal in trichloro ethylene that every part of the metal is exposed to trichloro ethylene.

7. After taking out the non-galvanized metal from the trichloro ethylene, hold it outside for half a minute - forty-five seconds that the remainder of trichloro ethylene on the metal vaporizes. Then, put the metal in the hydrochloric acid for 3 minutes. Make sure that every part of the metal is exposed to the hydrochloric acid.

8. After taking out the metal from the hydrochloric acid wash the metal with acetone to clean the acid on the metal.

9. Put the metals on the stands. Then put the water vapor producing machines right in front of the metals that the distances between the metals and water vapor producing machines are equal. Place papers around the water vapor producing machines and below the metals that the tables and the floor wouldn't get wet.

10. Run the water vapor producing machines with same rate of producing at their maximum capacities.

11. Stop the water vapor producing machines after 2 hours.

12. Wash the galvanized metal with acetone that every part of the metal is exposed to acetone enough. Then, wait until the acetone on the metal is totally vaporized.

13. Measure the mass of the galvanized metal with the electronic scale with an uncertainty of 0.001 g. Then, record it.

14. Wash the non-galvanized metal with acetone that every part of the metal is exposed to acetone enough. Then, wait until the acetone on the metal is totally vaporized.

15. Measure the mass of the non-galvanized metal with the electronic scale with an uncertainty of 0.001 g. Then, record it.

16. Measure the temperature of and pressure in the room with the thermometer and barometer. Make sure that there is no change in the temperature or the pressure.

17. Run the water vapor producing machines with same rate of producing at their maximum capacities.

18. Repeat steps 11, 12, 13, 14, 15, 16 and 17 at every 2 hours.

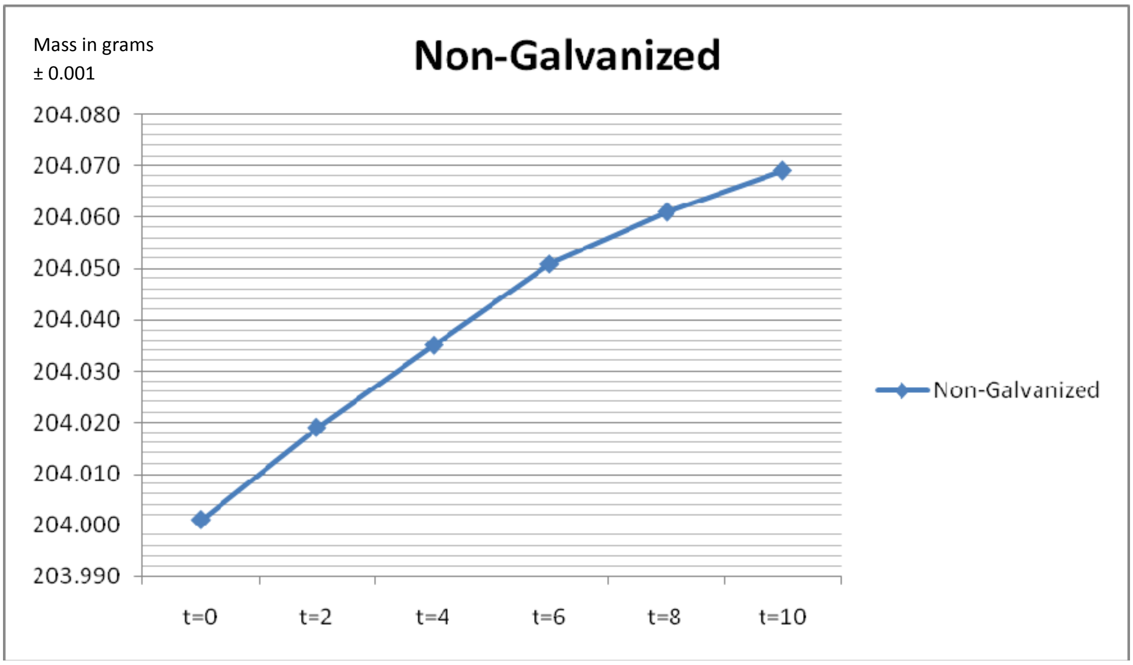
19. At 10^{th} hour, after doing steps 11, 12, 13, 14, 15, 16 and 17 put the metals wrap the metals with papers that the rust is not spread out in the room. Throw the papers around the water vapor producing machines in the garbage. Switch off the electronic scale, and unplug the electronic scale and water vapor producing machines.

DATA COLLECTION

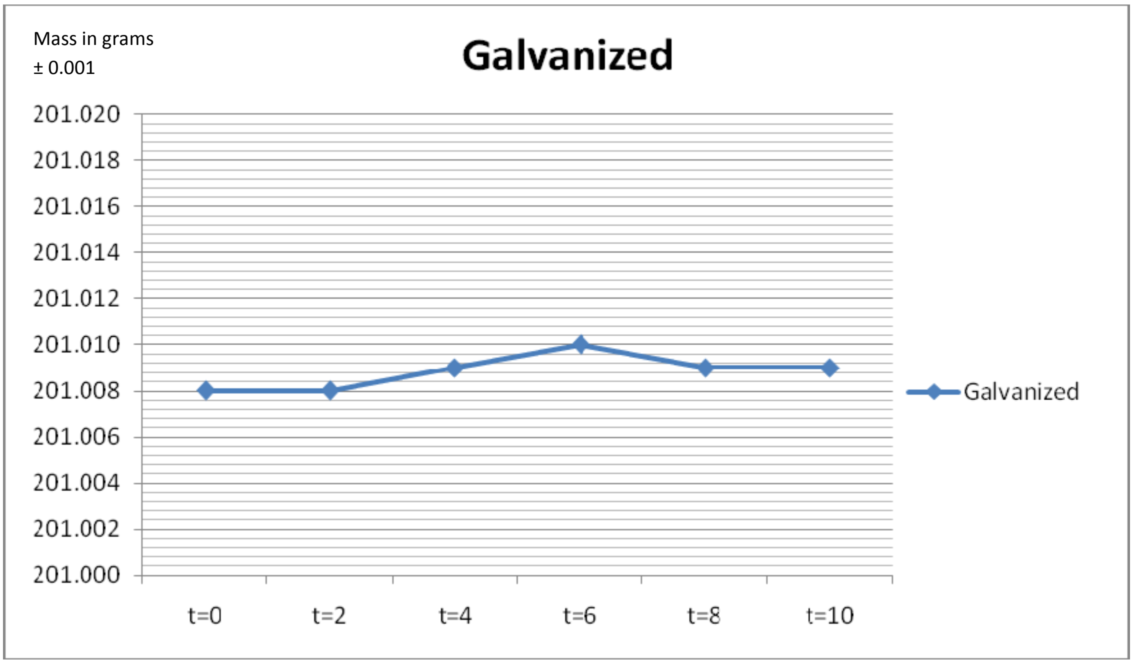
1st Trial:

Time (Hours)	Mass in Grams ± 0.001	
	Non-Galvanized Metal	**Galvanized Metal**
0	200.030	196.955
0 (with the wires)	204.083	201.008
0 (after the trichloro ethylene and hydrochloric acid procedure)	204.001	201.008
2	204.019	201.008
4	204.035	201.009
6	204.051	201.010
8	204.061	201.009
10	204.069	201.009

Table – 1: The mass readings for both metals of 1st trial at every 2 hours.



Graph – 1: The mass readings for non-galvanized metal of 1st trial at every 2 hours.

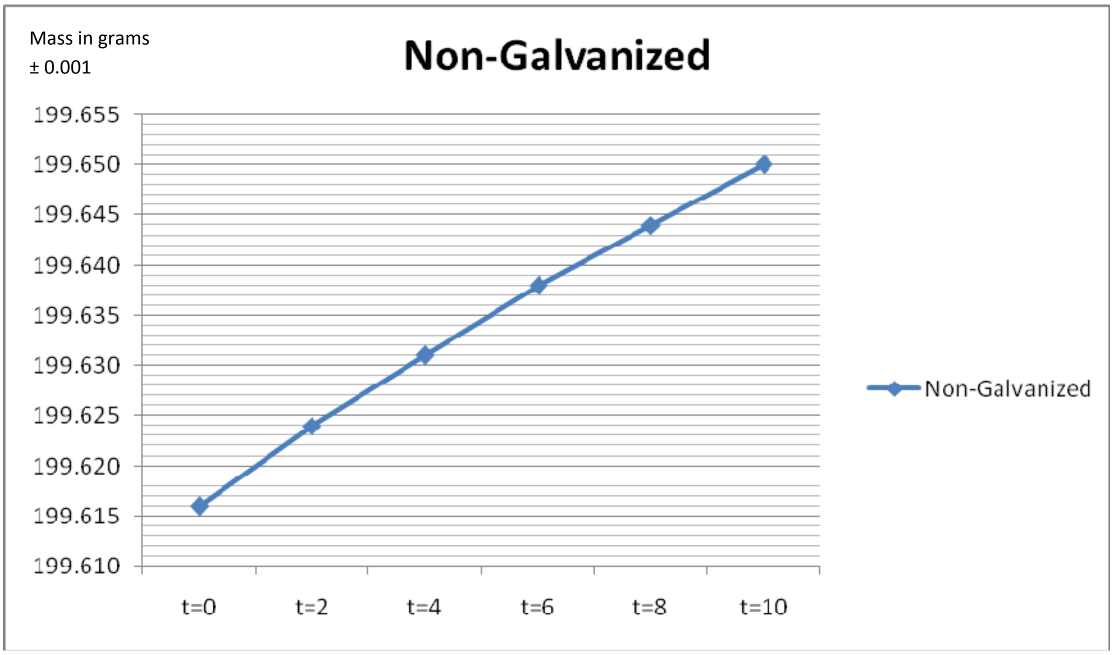


Graph – 2: The mass readings for galvanized metal of 1st trial at every 2 hours.

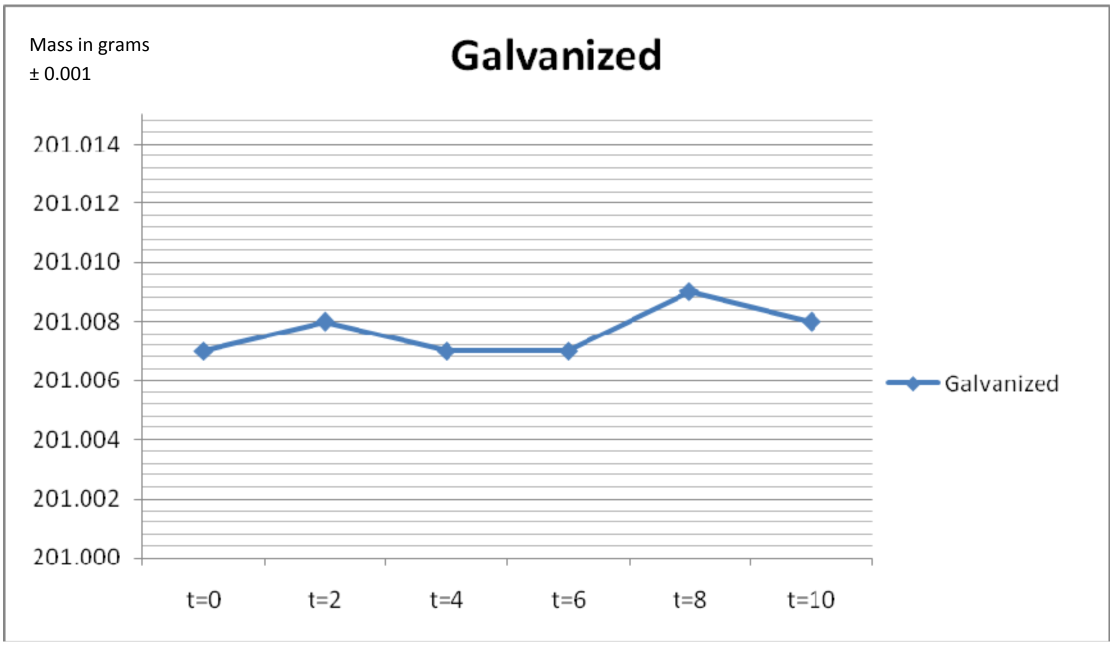
2nd Trial:

Time (Hours)	Mass in Grams ± 0.001	
	Non-Galvanized Metal	**Galvanized Metal**
0	195.413	196.747
0 (with the wires)	199.672	201.007
0 (after the trichloro ethylene and hydrochloric acid procedure)	199.616	201.007
2	199.624	201.008
4	199.631	201.007
6	199.638	201.007
8	199.644	201.009
10	199.650	201.008

Table – 2: The mass readings for both metals of 2nd trial at every 2 hours.



Graph – 3: The mass readings for non-galvanized metal of 2nd trial at every 2 hours.

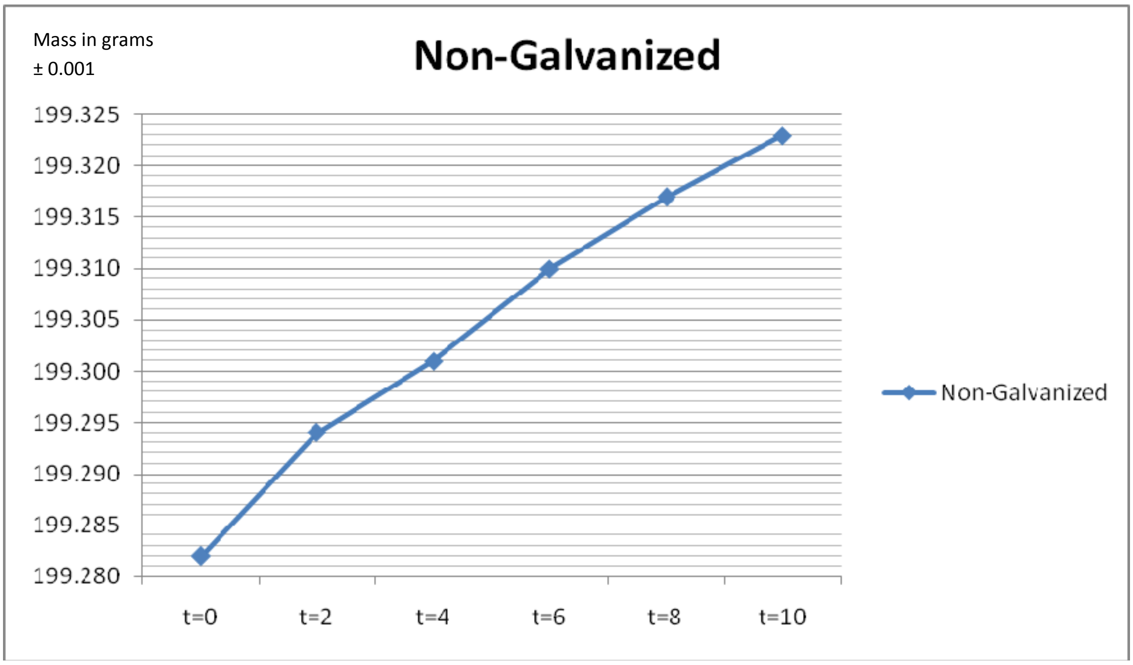


Graph – 4: The mass readings for galvanized metal of 2nd trial at every 2 hours.

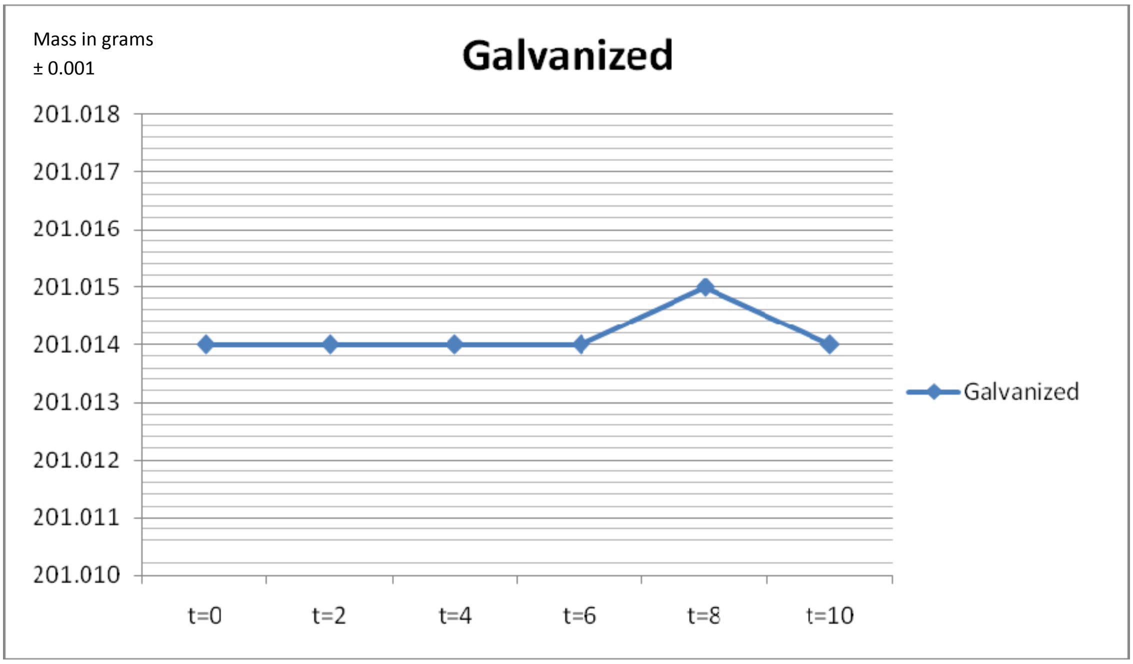
3rd Trial:

Time (Hours)	Mass in Grams ± 0.001	
	Non-Galvanized Metal	**Galvanized Metal**
0	195.156	196.781
0 (with the wires)	199.399	201.014
0 (after the trichloro ethylene and hydrochloric acid procedure)	199.282	201.014
2	199.294	201.014
4	199.301	201.014
6	199.310	201.014
8	199.317	201.015
10	199.323	201.014

Table – 3: The mass readings for both metals of 3rd trial at every 2 hours.



Graph – 5: The mass readings for non-galvanized metal of 3rd trial at every 2 hours.

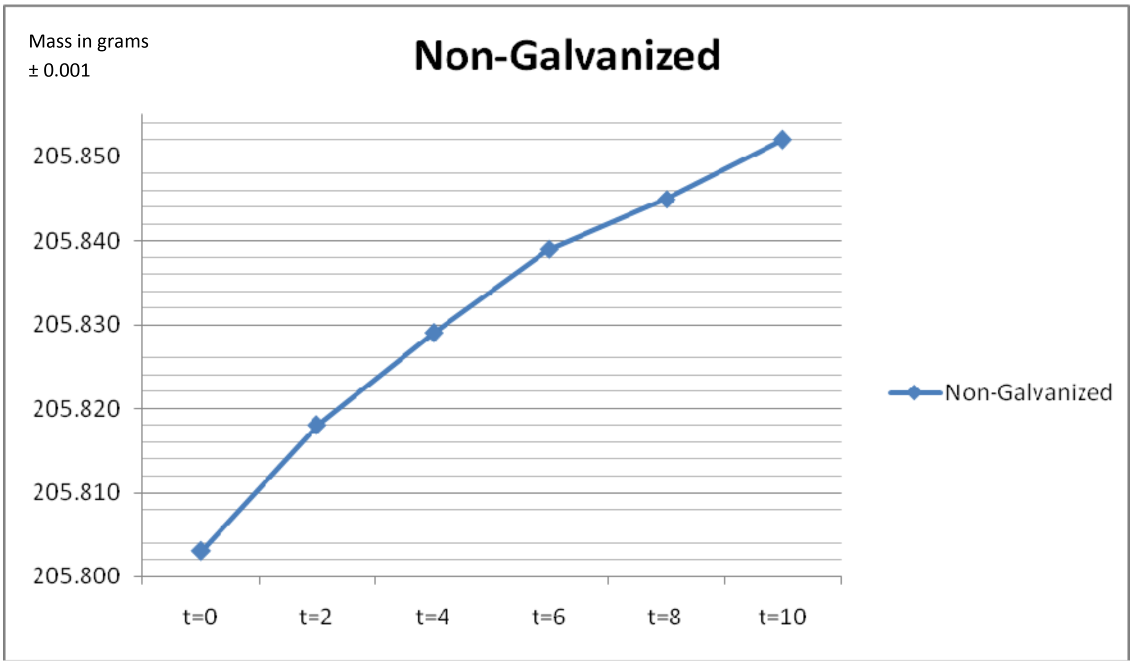


Graph – 6: The mass readings for galvanized metal of 3rd trial at every 2 hours.

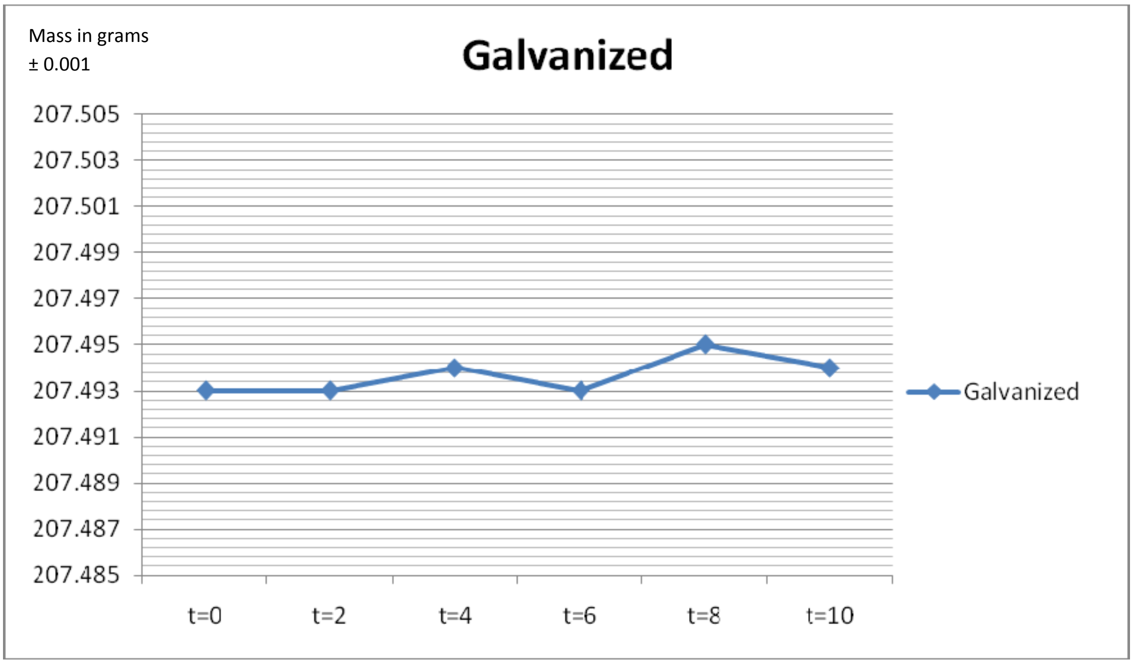
4th Trial:

Time (Hours)	Mass in Grams ± 0.001	
	Non-Galvanized Metal	**Galvanized Metal**
0	201.784	203.340
0 (with the wires)	205.911	207.493
0 (after the trichloro ethylene and hydrochloric acid procedure)	205.803	207.493
2	205.818	207.493
4	205.829	207.494
6	205.839	207.493
8	205.845	207.495
10	205.852	207.494

Table – 4: The mass readings for both metals of 4th trial at every 2 hours.



Graph – 7: The mass readings for non-galvanized metal of 4th trial at every 2 hours.

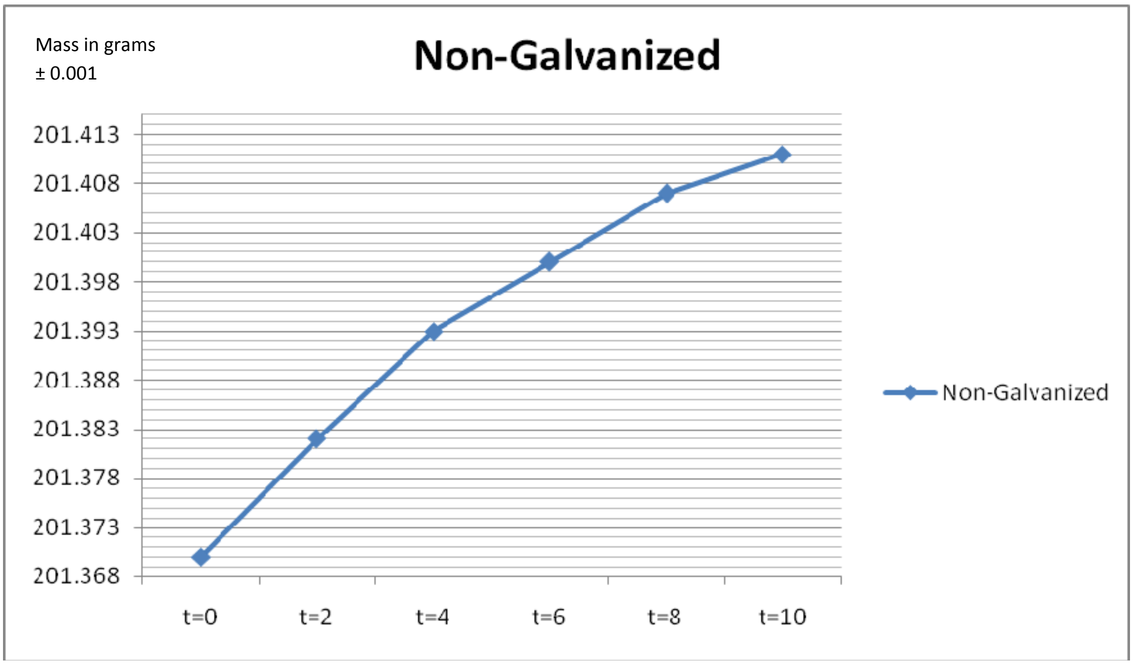


Graph – 8: The mass readings for galvanized metal of 4th trial at every 2 hours.

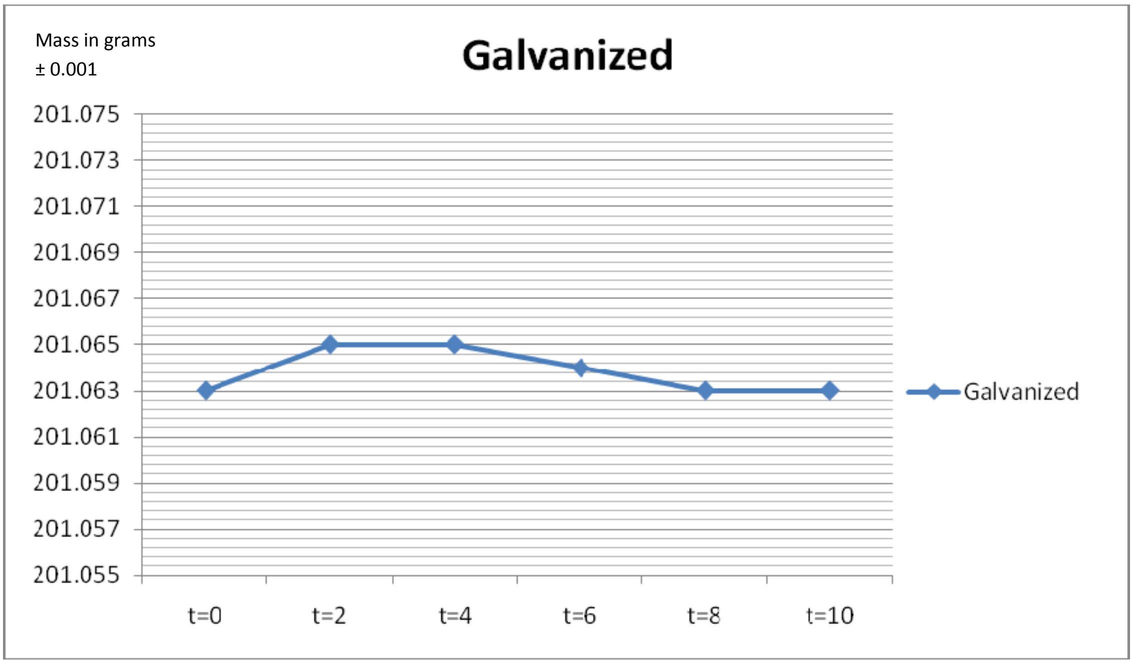
5th Trial:

Time (Hours)	Mass in Grams ± 0.001	
	Non-Galvanized Metal	Galvanized Metal
0	197.542	197.121
0 (with the wires)	201.443	201.063
0 (after the trichloro ethylene and hydrochloric acid procedure)	201.370	201.063
2	201.382	201.065
4	201.393	201.065
6	201.400	201.064
8	201.407	201.063
10	201.411	201.063

Table – 5: The mass readings for both metals of 5th trial at every 2 hours.



Graph – 9: The mass readings for non-galvanized metal of 5th trial at every 2 hours.



Graph – 10: The mass readings for galvanized metal of 5th trial at every 2 hours.

Qualitative Observation:

Galvanized metal: There was no change in the color of the metal. One difference was that the number of droplets on this metal looked much more than the number of droplets on the other metal.

Non-Galvanized metal: The metal's color changed in time. It turned into orange-brown mix which is the color of rust.

DATA ANALYSIS

Mean value of the mass of oxygen involved in metal in 10 hours:

[(Mass involved in Trial 1) + (Mass involved in Trial 2) + (Mass involved in Trial 3) + (Mass involved in Trial 4) + (Mass involved in Trial 5)] / 5 = (0.068 + 0.034 + 0.041 + 0.049 + 0.041) / 5 = 0.047 g

Mean value of the mass of oxygen involved in metal in 1 hour:

(Average mass involved in 10 hours) / 10 = 0.047 / 10 = 0.005 g / hr (Rate of corrosion)

ERROR CALCULATION

The literature value is the mean mass involved in metal in 10 hours.

1st Trial:

Percentage Error = [| Observed Value – Literature Value | / Literature Value] x 100

[| 0.068 ± 0.001 – 0.047 ± 0.001| / 0.047 ± 0.001] x 100 = 45 % Error

2nd Trial:

Percentage Error = [| Observed Value – Literature Value | / Literature Value] x 100

[| 0.034 ± 0.001 – 0.047 ± 0.001 | / 0.047 ± 0.001] x 100 = 28 % Error

3th Trial:

Percentage Error = [| Observed Value – Literature Value | / Literature Value] x 100

[| 0.041 ± 0.001 – 0.047 ± 0.001 | / 0.047 ± 0.001] x 100 = 13 % Error

4th Trial:

Percentage Error = [| Observed Value – Literature Value | / Literature Value] x 100

[| 0.049 ± 0.001 – 0.047 ± 0.001 | / 0.047 ± 0.001] x 100 = 4 % Error

5th Trial:

Percentage Error = [| Observed Value – Literature Value | / Literature Value] x 100

[| 0.041 ± 0.001 – 0.047 ± 0.001 | / 0.047 ± 0.001] x 100 = 13 % Error

CONCLUSION and EVALUATION

My research question was ***if galvanization is an effective method to produce a durable water reservoir.*** In my experiment, the galvanized metal pieces were pieces that could form water reservoirs. Therefore, I tested the durability of the galvanized metals of a possible piece of a water reservoir.

In the experiment, there were significant differences between the metals after they were exposed to water vapor. I observed increase in the masses of non-galvanized metal pieces in all 5 trials. The increase in mass was a signal of corrosion that the amount of increase in mass is inversely proportional with the durability of the metal. The water reservoirs should be durable enough to be used for 5 years, 10 years, 20 years. The average increase of 0.047 g of mass in 10 hours for a small piece of metal is a significant amount of increase as 10 hours is a very short period of time. If the water reservoirs were made of that non-galvanized metal, maybe that reservoirs had to be replaced with the new ones every day. Such replacement is impossible for every water reservoir in a city, in a world. In addition, the pictures of the non-galvanized metals after 10 hours in the appendix are exemplifying the need of replacement for those metals.

However, the galvanized metals didn’t show similar properties. I observed 0.001 or 0.002 grams of increase in the masses of galvanized metals but at the end, the masses of most of the galvanized metals decreased back to their original. As 0.001 gram is the uncertainty value of the weight that I used, 0.001 g increase in mass means no increase. The same reason resulted in no slopes in the graphs of the mass recordings of galvanized metals. If there were even small amounts of increase in the masses, than I would be able to calculate slopes for the graphs and have predictions about in how many months, years the galvanized metals would become useless. As there was no increase in the masses of the galvanized metals, the galvanized metals are so durable that one can’t find a clue of corrosion in a short period of time. That also replies my research question: ***galvanizing metals is effective enough to create durable water reservoirs.*** As there is no slope in my graphs, I couldn’t calculate an average time period for in how many years a galvanized piece of metal becomes useless. However, the water reservoirs that are produced from galvanized metals are being used about 20-30 years in Ankara. That 20-30 years of time is an effective time period.

In addition, the graphs of the data collected show a different aspect of corrosion. The curves of the graphs are changing; the slopes of the graphs are decreasing. One possible reason for this may be the decreasing of the surface areas of the metals. As the surface areas decrease, the involvement chance of oxygen may be decreasing. If the graph would continue like this, when the whole surface area of a metal is totally oxidized the corrosion would then stop.

Last but not the least, some of the percentage errors in my experiment are so high. The reason for that is, the increases in masses were so low which were expressed with numbers such as 10^{-3}. Therefore, the percentage errors came out so high. Although the percentages look high, the percentage of the difference in grams to the total mass of the metals would come out so low.

EVALUATION of THE METHOD

I think that the experiment method that I developed myself worked pretty well. The main reason for this was of course the solutions that I adapted to the problems aroused in my mind which I also introduced in the **Introduction** part of my extended essay. However, there were still two problems. First, the weight may be affected by any movement in the room such as movement of air, as the experiment depends on so small numbers of grams, a very small movement can affect the calculations. The second possible problem was that the acetone may not be fully effective in vaporizing the water droplets. The reason for 0.001 or 0.002 g of increase in masses of galvanized metals may be the usage of acetone. Otherwise, I believe that the method was effective enough to bring out accurate results. However, one another problem was about time. In my experiment, a metal with overall of 200 g showed 0.040-0.050 g increase in mass. The percentage of increase to the original mass is so low. Therefore, doing the experiment for days instead of 10 hours may give some information about the increase in mass of a galvanized metal.

APPENDIX

Pictures from my experiment:

Picture – 6: While I am pouring trichloro ethylene.

Picture – 7: The process of trichloro ethylene.

Picture – 8: The process of hydrochloric acid.

Picture – 9: A picture from my experiment.

Picture – 10: A picture from my experiment.

Picture – 11: A picture from my experiment.

Picture – 12: A picture from my experiment.

Picture – 13: A picture of non-galvanized metal after 6 hours.

Picture – 14: A picture of non-galvanized metal after 2 hours.

Picture – 15: A picture of galvanized metal after 10 hours.

Picture – 16: A picture of the electronic scale that I used.

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