Gonca Başak Çorak

D001129-0037

EXTENDED ESSAY

-Chemistry-

Is there a plastic which can be decomposed by bacteria and other living organisms within the environment over a specific time interval which is also called biodegradable plastic?

Word Count: 3757

GONCA BAŞAK ÇORAK

MAY 2014

CONTENTS

ABSTRACT

In this experiment I have investigated the research question: "Is there a plastic which can be decomposed by bacteria and other living organisms within the environment over a specific time interval which is also called biodegradable plastic?"

This experiment was done in order to indicate if there was a plastic that could be dissolved faster and easier than other usual plastics like nylons under environmental conditions and which can also solve the global waste problem of plastics. From this experiment and the results of the experiment it was seen that biodegradable plastics were in existence and they would decompose more in a specific time interval than usual plastics would decompose.

In the experiment, firstly nylon 6,10 and biodegradable plastic was synthesized and same amount of plastics were collected. Then these plastics were buried into the soil for 180 days and from this the decomposition rates of the biodegradable plastic and the nylon 6,10 used in the experiment was calculated for 180 days.

Although the ASTM's biodegradability method focused on the amount of the carbon that converted into the carbondioxide at the end of the 180 days, in this experiment the decomposition rates of the plastics were calculated and detected by the change in masses of the plastics over 180 days. But from the data obtained from this experiment, it was seen that there were a lot of systematic errors that caused by this mass change technique which showed that this technique was not appropriate to detect the decomposition rates of the biodegradable plastic and nylon 6,10 over 180 days.

Word Count: 259

INTRODUCTION

Plastic is a synthetic material made from a wide range of organic polymers and a substance that can be moulded into shape. Plastics have many uses in our daily lives. It is the most common substance that can be found in our kitchen, textile industry, health industry, civil engineering and electric engineering, and so on. For example, polystyrene (PS) is used in disposable cups, plates, food containers; polyester (PES) in textile; polyethylene (PE) in supermarket bags, plastic bottles; polyamide (PA) in fishing line, toothbrush and polycarbonate and polycarbonate (PC) in eyeglasses, traffic lights and lenses.

As one of the most common substances in our lives, plastics have a big role on disrupting the environmental system and order of the earth because they cannot be decompose in nature for centuries. Serious environmental threats from plastics include the increasing presence of microplastics in the marine food chain, excess carbon emission when they are burned down due to the main material they are generally made up of: petroleum. Plastics have many other effects on the environment and one of the materials that may have caused the climate change although they are extremely useful in our daily lives.

Because of their negative effects on the environmental systems, scientists produced a plastic which can be easily decomposed in the nature under aerobic or anaerobic conditions and this plastic is called biodegradable plastic. Biodegradable plastics are basically plastics which are capable of being decomposed by bacteria or other living organisms. Biodegradable plastics are seen as a promising solution for the climate change because they are eco-friendly. They can be derived from renewable feedstocks, therefore reducing greenhouse gas emission. American Society for Testing and Materials (ASTM International) defines methods to test biodegradable plastics, both aerobic and anaerobic as well as in marine ecosystem. Having read and seen the existence of biodegradable plastics and the experiment done to make them more useful and stronger, a question came to my head: Is there really a plastic which can be decomposed easily under aerobic and anaerobic conditions by bacteria or other living organisms? What are the ASTM standards for a plastic to be counted as a biodegradable plastic? Is it easy and possible to produce a biodegradable plastic under home conditions?

According to ASTM International, a biodegradable plastic should be able to be decomposed in carbon level to carbon dioxide by %60 over a period of 180 days and in order to calculate this change in carbon level of the plastic a feedback controlled pilot-scale compositing set-up should be used. In my experiment, in order to see if there really is biodegradable plastic, I examined the change of the mass of nylon and the biodegradable plastic which had the same initial mass over a period of time of 180 days. If the change in the mass of the biodegradable plastic is over %60 decomposition, it will prove to me that the plastic is biodegradable. I will discuss the effectiveness of this change in mass technique on biodegradable plastic and nylon in my conclusion.

RESEARCH QUESTION

Is there a plastic which can be decomposed by bacteria and other living organisms within the environment over a specific time interval which is also called biodegradable plastic?

BACKGROUND INFORMATION

3.1. Information on Plastics and Biodegradable Plastics

Plastics are the materials which are also called polymers and made up of smaller subunits of different monomers. They can be given shape or molded into any shape. Chemists combine various monomers in order to obtain various plastics. Most plastics do not react chemically with other substances and this is why they are widely useful in our daily lives [1]. But being unreactive with other substances, it causes plastics to not being able to decompose and the main global issue of impacts of plastics on the environment derives from here. And also plastics contain some materials that can be dangerous for human beings. Chemicals added to plastics are absorbed by human bodies and some of these compounds have been found to alter hormones and potential human health effects [2].

Because they are unreactive, plastics cannot decompose inside soil by any living organisms and they remain the same at amount inside the soil causing soil degradation. Therefore, plastic disposal poses a difficult and significant environmental problem. Plastics remain around the environment for centuries, and recycling seemed to be the best solution for this environmental problem. After the discovery of biodegradable plastics, these plastics seemed to be the promising solution for this environmental problem because biodegradable plastics are the plastics which can be decomposed naturally by bacteria or other living organisms within the environment.

The decomposition of the biodegradable plastics are achieved when a microorganism break down the structure of the plastic. The end result of this decomposition is less harmful to the environment than normal, traditional plastics. Biodegradable plastics are made up from all natural plant materials which can be: corn oil, starch and orange peels. Because the biodegradable plastics do not contain any chemical material inside them, when they are decomposed they do not harm the environment by releasing any toxic material and they can be easily decomposed in to their components by microorganisms in the environment. Because of not holding carbon atoms after the formation like traditional plastics, biodegradable plastics do not release any greenhouse gases into the atmosphere [3].

Because of these properties of biodegradable plastics, it is believed that these plastics can solve the environmental problem caused by insolubility of traditional plastics and their impacts on the environment and scientist are trying to improve the properties of these biodegradable plastics, so that they can be used in every area in our daily lives.

American Society for Testing and Materials (ASTM International) is an international standards organization which discovers and develops the standards of various materials, products and systems. One of the international standards for a plastic to be considered as biodegradable is ASTM D6400- standard specification for compostable plastics. According to ASTM D6400, the carbon level of the biodegradable plastic should be converted into carbon dioxide by %60 over a period of time of 180 days [4]. And also there should not be any evidence of toxic material where the plastic is left to be decomposed after this time period. If a plastic ensure these criteria, it is accepted as a biodegradable plastic according to ASTM.

3.2. The Synthesis of Nylon 6, 10

Nylon 6, 10 (PA610) is semi crystalline polyamide commonly used in monofilament form in applications such as bristles and brushes [5]. In order to synthesize nylon 6,10 a polymerization reaction is involved which involves hexane-1,6-diamine and sebacoyl chloride. In order to synthesize nylon 6,10, the amine molecule must have a $–NH_2$ group at each end, and the acid chloride must have a –COCl group at each end. Then the diamine and acid chloride bond together, end-on-end, to form very long chains and the synthesis of nylon 6,10 results in the production of hydrochloric acid [6].

Overall Reaction: Polymerization

$$NH_2\text{-}(CH_2)_6\text{-}NH_2 \;+\; COCl\text{-}(CH_2)_8\text{-}COCl \longrightarrow \left[NH\text{-}(CH_2)_6\text{-}NH\text{-}CO\text{-}(CH_2)_8\text{-}CO \right]_n + HCl$$

hexane-1,6-diamine — sebacoyl chloride — nylon 6,10

Mechanism for Nylon 6,10 Polymerization[6]

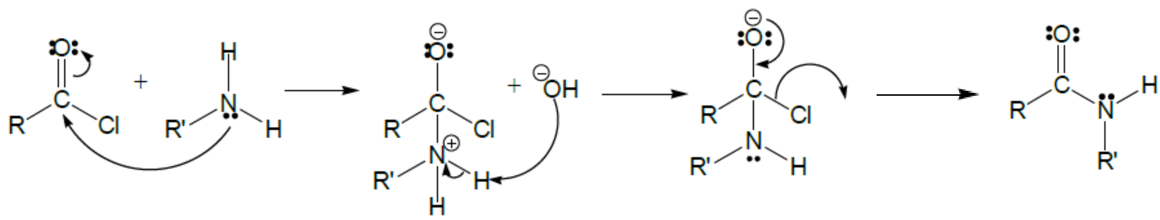


Fig.1 the acid chloride within the sebacoyl chloride and the amine within the hexane-1,6-diamine combines in order to produce an amide which causes the polymerization of nylon 6,10

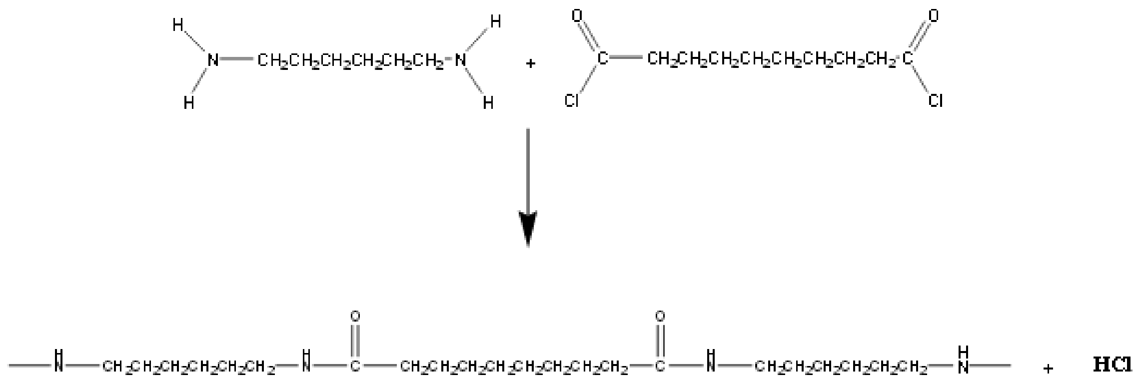


Fig. 2 The open equation of nylon 6,10 polymerization

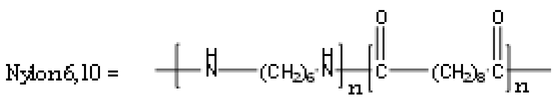


Fig. 3 Formula of nylon 6,10

3.3. The Synthesis of a Biodegradable Plastic

The ASTM defines biodegradable plastic as "a plastic in which all the organic carbon can be converted into biomass, water, carbon dioxide, and/or methane via the action of naturally occurring microorganisms such as bacteria and fungi, in timeframes consistent with the ambient conditions of the disposal method." [7] Biodegradable plastics are mainly made up of the mixture of starch, water, glycerol and ethanoic acid. Glycerol is used for making the biodegradable plastic flexible when without glycerol, the biodegradable plastic is fairly stiff. So we can say that glycerol used in the biodegradable plastic synthesis acts like a plasticizing agent. When the mixture is heated and mixed in order to obtain the biodegradable plastic, ethanoic acid hydrolyzes and breaks the bound between the branches within starch and this reaction ends up with the production of long linear chains of polysaccharides of sugar. And by this way the biodegradable plastic is obtained and produced. [8]

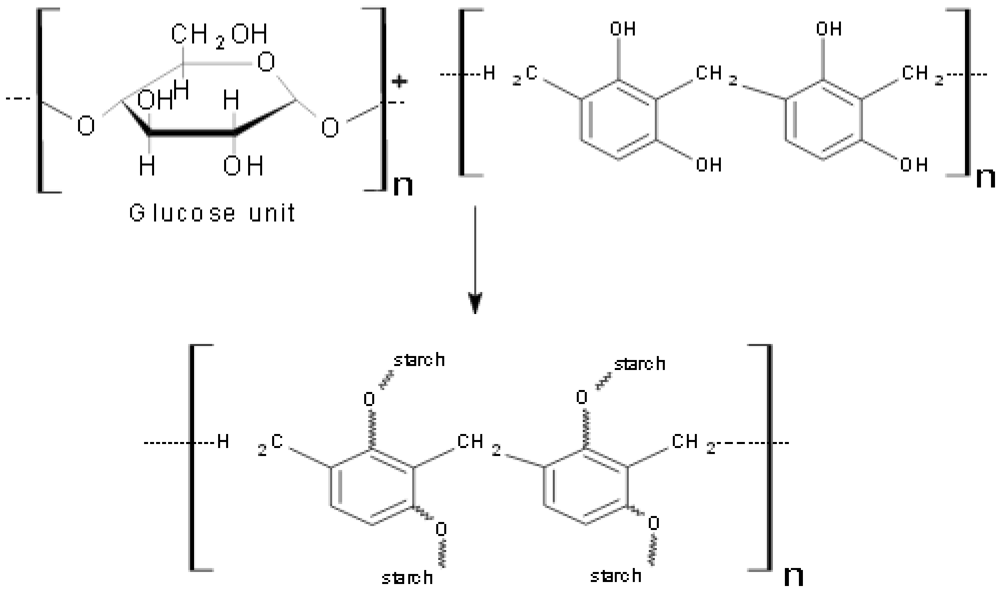


Fig. 4 how long linear chains of polysaccharides of sugar is produced when the mixture for the synthesis of biodegradable plastic is heated [9]

VARIABLES

4.1. Independent Variable: Type of the plastic: nylon 6,10 or biodegradable plastic

4.2. Dependent Variable: Change in mass of the plastic

4.3. Controlled Variables: Time interval which is 180 days

Volume of water used for synthesis of nylon 6,10 which is 50mL for each trial

Mass of hezane-1,6-diamino used for synthesis of nylon 6,10 which is 5g for each trial

Mass of Na_2CO_3 used for synthesis of nylon 6,10 which is 0.5g for each trial

Volume of hexane used for synthesis of nylon 6,10 which is 10mL for each trial

Volume of sebacoyl chloride used for synthesis of nylon 6,10 which is 1mL for each trial

Initial mass of nylon 6,10 which is approximately 5g taken from each trial

Volume of water used for synthesis of biodegradable plastic which is 60mL for each trial

Mass of starch used for synthesis of biodegradable plastic which is 9.5g for each trial

Volume of glycerol used for synthesis of biodegradable plastic which is 5mL for each trial

Volume of acetic acid used for synthesis of biodegradable plastic which is 5mL for each trial

Initial mass of the biodegradable plastics which is approximately 5g taken from each trial

Temperature of the experimental system which is 25°C

Amount of topsoil used for burying the plastics which is 30cm for each trial

Depth of the plastics buried into the flowerpots which is 15cm for each trial

Nutrients of the soil where the plastics are buried

METHOD

[See Appendix I for the full apparatus and chemical lists.]

5.1. Synthesis of Nylon 6,10

5.1.1. Into one 250mL beaker pour 50mL of distilled water by using one graduated cylinder.
5.1.2. Into water, pour 5g of hexane-1,6-diamine measured by scale and with the help of magnetic stirrer bar and the hot plate magnetic stirrer, solve the hexane-1,6-diamine within water.
5.1.3. Pour 0.5g of Na_2CO_3 measured by scale and solve with the hot plate magnetic stirrer. This mixture is the *hexan-1,6-diamine solution*.
5.1.4. Into the other 250mL beaker (Beaker II) pour 100mL of n-hexane by graduated cylinder.
5.1.5. Into beaker II, pour 1mL of sebacoyl chloride by dropper and stir the mixture by using the other magnetic stirrer bar and the hot plate magnetic stirrer. This mixture is the *sebacoyl chloride solution*.
5.1.6. Pour the sebacoyl chloride solution into the hexane-1,6-diamine solution very slowly and carefully. A thin layer between these two solutions will be occurred.
5.1.7. By using a forceps, get this thin layer and wrap it around a stirring rod and keep on wrapping until the mixtures are finished and no nylon is existed.
5.1.8. Wash the nylon 6,10 produced with distilled water and let it dry for a day.
5.1.9. Take 5grams of nylon 6,10 measured by the electronic scale.
5.1.10. Repeat these steps in order to obtain 10 different trials.

5.2. Synthesis of Biodegradable Plastic

5.2.1. Into the 250mL beaker pour 60mL of distilled water by measuring with a graduated cylinder.
5.2.2. Pour 9.5g of starch measured by the scale into the beaker and until it is homogenous like solution stir the solution by magnetic stirrer bar and hot plate with magnetic stirrer.
5.2.3. After the solution becomes homogenous like, pour 5mL of glycerol into the solution and keep on stirring by the hot plate magnetic stirrer.
5.2.4. Pour 5mL of acetic acid (%5 concentration) into the beaker and keep on stirring.
5.2.5. Turn on the heater to the 200°C of the hot plate magnetic stirrer and turn the stirrer speed to 1 and by the magnetic stirrer bar, stir the solution for 20minutes controlled by stopwatch-until the solution becomes transparent.
5.2.6. When solution becomes transparent, get the solution form the hot plate magnetic field and pour the solution into one petri dish and left for cooling.
5.2.7. Separate the biodegradable plastic from the petri dish when it is cooled.
5.2.8. Repeat step 5.2.6 and 5.2.7 until there is no solution left in the beaker.
5.2.9. Take 5 grams of the biodegradable plastic produced by measuring with the electronic scale.
5.2.10. Repeat these steps in order to obtain 10 different trials.

5.3. Burying Nylon 6,10 and Biodegradable Plastic into the Soil

5.3.1. Into both of the flowerpots, pour 15cm of the soil by measuring it by 30cm ruler.
5.3.2. Into one of the flowerpots, put the 5gram nylon6,10 and label the flowerpot as ‘nylon 6,10’.
5.3.3. Into the other flowerpot, put 5 gram of biodegradable plastic and label the flowerpot as ‘biodegradable plastic’.
5.3.4. Into both of the flowerpots, pour 15cm of soil onto the plastics by measuring it by 30cm ruler.
5.3.5. Repeat these steps for 10 times in order to obtain 10 different trials for nylon 6,10 and 10 different trials for biodegradable plastic.
5.3.6. Keep plastic in the flowerpots for 180days.

5.4. Obtaining Nylon 6,10 and biodegradable Plastic after 180 days

5.4.1. After 180days since the plastics are buried into the flowerpots, in order to obtain the remaining pieces of plastic, pour one of the flowerpots into the bucket.
5.4.2. Pour 1L of water into the bucket and stir the mixture with a stirrer.
5.4.3. Wait until the soil sinks and plastic to float.
5.4.4. After plastics are floating, collect the plastics from the surface of the water.
5.4.5. Let the plastics dry for 5 minutes, controlling by stopwatch.
5.4.6. After 5 minutes use an electronic scale to measure the final masses of the plastics.
5.4.7. Repeat these steps for 20 flowerpots in order to obtain 10 different trials for nylon 6,10 and 10 different trials for biodegradable plastic.

DATA COLLECTION

TRIALS	Volume of water /mL (±0.5mL)	Mass of hexane-1,6-diamine /g (±0.01g)	Mass of Na_2CO_3 /g (±0.01g)	Volume of hexane /mL (±0.5mL)	Volume of sebacoyl chloride /mL (±0.5mL)	Initial mass /g (±0.01g)	Final mass /g (±0.01g)
1	50.0	5.00	0.50	100.0	1.0	5.00	4.98
2	50.0	5.00	0.50	100.0	1.0	4.99	4.25
3	50.0	5.00	0.50	100.0	1.0	5.03	4.80
4	50.0	5.00	0.50	100.0	1.0	4.92	4.75
5	50.0	5.00	0.50	100.0	1.0	5.00	4.97
6	50.0	5.00	0.50	100.0	1.0	4.96	4.99
7	50.0	5.00	0.50	100.0	1.0	4.96	4.87
8	50.0	5.00	0.50	100.0	1.0	5.00	4.92
9	50.0	5.00	0.50	100.0	1.0	5.00	4.87
10	50.0	5.00	0.50	100.0	1.0	5.01	4.98

Table1. Initial and final masses of 10 trials of nylon 6,10 with the material used for the synthesis of the plastics

Qualitative Data for Nylon 6,10: Before mixing the two solutions, the hexane-1,6-diamine solution get a yellowish color after the hexan-1,6-diamine was dissolved in the water, although the sebacoyl chloride solution was white and transparent. After mixing the solutions by pouring slowly, a layer between the two solutions occurred and while pouring the sebacoyl chloride solution into the hexan-1,6-diamine solution, some amount of vapour was released due to the sudden reaction between the two solutions. When the layer between the two solutions which produced the nylon 6,10, was extracted the transparency of the material decreased and by this way the nylon which is produced from the extraction of the layer lost its previous quality of being transparent. Other than the visual change of the solutions and the nylon, the materials used in the synthesis of nylon 6,10 had sharp smells. Especially, hexane-1,6-diamine had the sharpest smell that caused my nose to be uncomfortable.

TRIALS	Volume of water /mL (±0.5mL)	Mass of starch /g (±0.01g)	Volume of glycerol /mL (±0.5mL)	Volume of acetic acid /mL (±0.5mL)	Initial mass /g (±0.01g)	Final mass /g (±0.01g)
1	60.0	9.50	5.0	5.0	4.95	2.40
2	60.0	9.50	5.0	5.0	4.96	2.35
3	60.0	9.50	5.0	5.0	5.02	2.18
4	60.0	9.50	5.0	5.0	5.02	2.32
5	60.0	9.50	5.0	5.0	4.91	2.26
6	60.0	9.50	5.0	5.0	4.98	2.28
7	60.0	9.50	5.0	5.0	5.00	2.35
8	60.0	9.50	5.0	5.0	4.99	2.28
9	60.0	9.50	5.0	5.0	5.00	2.37
10	60.0	9.50	5.0	5.0	5.00	2.35

Table2. Initial and final masses of 10 trials of biodegradable plastic with the material used for the synthesis of plastic

Qualitative Data for Biodegradable Plastic: When starch was added into the water, water lost its transparency and got a whitish color since the color of the starch used was white and the solution become opaque. But as the solution was stirred and heated by the magnetic stirrer bar and hot plate, it lost its whitish color and became more transparent, like it was almost a hundred percent transparent. After the solution was ready to be poured into the petri dishes, the biodegradable plastic was almost transparent like the almost transparent solution that it is produced of. Besides the visions, the smell of the starch made my nose uncomfortable but not as much as hexane-1,6-diamine did while synthesizing nylon 6,10 and the smell of the solution was sharp too due to the starch used in it.

DATA PROCESSING

7.1. Changes in the mass of the plastics are calculated by subtracting the final mass of the plastic from its initial mass. The uncertainty of the mass change is calculated by adding the uncertainty of the initial mass (±0.01g) and the uncertainty of the final mass (±0.01g), which all of the uncertainties of the mass change over 180days time period will be equal to ±0.02g.

$$change\ in\ mass(\Delta m) = initial\ mass(m_i) - final\ mass(m_f)$$

For nylon 6,10; trial1:

Initial mass: 5.00±0.01g final mass: 4.98±0.01g

Δm = 5.00 – 4.98 = 0.02±0.02g

For biodegradable plastic; trial1:

Initial mass: 4.95±0.01g final mass: 2.40±0.01g

Δm= 4.95 – 2.40 = 2.55±0.02g

	Nylon 6,10		
TRIALS	**Initial Mass /g (±0.01g)**	**Final Mass /g (±0.01g)**	**Change in Mass /g (±0.02g)**
1	5.00	4.98	0.02
2	4.99	4.25	0.74
3	5.03	4.80	0.23
4	4.92	4.75	0.17
5	5.00	4.97	0.03
6	4.96	4.99	0.03
7	4.96	4.87	0.09
8	5.00	4.92	0.08
9	5.00	4.87	0.13
10	5.01	4.98	0.03

Table3. Change in mass of the nylon 6,10 produced in the experiment after 180days time interval with the initial and final mass values

	Biodegradable Plastic		
TRIALS	**Initial Mass /g (±0.01g)**	**Final Mass /g (±0.01g)**	**Change in Mass /g (±0.02g)**
1	4.95	2.40	2.55
2	4.96	2.35	2.61
3	5.02	2.18	2.84
4	5.02	2.32	2.70
5	4.91	2.26	2.65
6	4.98	2.28	2.70
7	5.00	2.35	2.65
8	4.99	2.28	2.71
9	5.00	2.37	2.63
10	5.00	2.35	2.65

Table4. Change in mass of the biodegradable plastics produced in the experiment after 180days time interval with the initial and final mass values

7.2. Decomposition percentage of the plastic is calculated by multiplying the change in mass value of the plastic with 100 and dividing the result into the initial mass value of the plastic. For the uncertainty of the decomposition percentage, the percentage error of the mass change and the initial mass is calculated by subtracting the percentage error of the initial mass from the percentage error of the change in mass.

$$Decomposition\ \% = \frac{100 \times change\ in\ mass}{initial\ mass}$$

For nylon 6,10; trial1:

Change in mass= 0.02±0.02g= 0.02g±100.00% initial mass: 5.00±0.01g= 5.00 ±0.20%

Decomposition% = (100×0.02) : 5.00 = 0.40%

Uncertainty (percentage error)= 100.0%-0.2% = ±99.8%

For biodegradable plastic; trial1:

Change in mass= 2.55±0.02g= 2.55±0.78% initial mass: 4.95±0.01g= 4.95±0.20%

Decomposition% = (100×2.55):4.95 = 51.51%

Uncertainty (percentage error) = 0.78%-0.20% = ±0.58%

	Nylon 6,10					
TRIALS	**Change in Mass /g (±0.02g)**	**Uncertainty of change in mass (±)**	**Initial Mass /g (±0.01g)**	**Uncertainty of initial mass (±)**	**Decomposition %**	**Uncertainty(±) of decomposition%**
1	0.02	%100.00	5.00	%0.20	0.40	%99.80
2	0.74	%2.70	4.99	%0.20	14.83	%2.50
3	0.23	%8.70	5.03	%0.20	4.57	%8.50
4	0.17	%11.76	4.92	%0.20	3.45	%11.56
5	0.03	%66.67	5.00	%0.20	0.60	%66.47
6	0.03	%66.67	4.96	%0.20	0.60	%66.47
7	0.09	%22.22	4.96	%0.20	1.81	%22.02
8	0.08	%25.00	5.00	%0.20	1.60	%24.80
9	0.13	%15.38	5.00	%0.20	2.60	%15.18
10	0.03	%66.67	5.01	%0.20	0.59	%66.47

Table5. Decomposition percentages of nylon 6,10 after 180days time interval with their initial masses and changes in mass values

	Biodegradable Plastic					
TRIALS	**Change in Mass /g (±0.02g)**	**Uncertainty of change in mass (±)**	**Initial Mass /g (±0.01g)**	**Uncertainty of initial mass (±)**	**Decomposition %**	**Uncertainty(±) of decomposition%**
1	2.55	%0.78	4.95	%0.20	51.51	%0.58
2	2.61	%0.77	4.96	%0.20	52.62	%0.57
3	2.84	%0.70	5.02	%0.20	56.57	%0.50
4	2.70	%0.74	5.02	%0.20	53.78	%0.54
5	2.65	%0.75	4.91	%0.20	53.97	%0.55
6	2.70	%0.74	4.98	%0.20	54.22	%0.54
7	2.65	%0.75	5.00	%0.20	53.00	%0.55
8	2.71	%0.74	4.99	%0.20	54.31	%0.54
9	2.63	%0.76	5.00	%0.20	52.60	%0.56
10	2.65	%0.75	5.00	%0.20	53.00	%0.55

Table6. Decomposition percentages of biodegradable plastics after 180days time interval with their initial masses and changes in mass values

7.3. Average decomposition percentage of the plastics are calculated by adding the decomposition% values of all trials of a specific plastic and then dividing the result into 10. Theoretical value of nylon fibers to decompose a hundred percent in landfill conditions is up to 40 years (480months)[10]. For this experiment according to the given theoretical value, I calculated that nylon 6,10 should be dissolved by 1.25% in 6 month period. The theoretical value of the rate of decomposition of biodegradable plastic over 6 month time period is %60.

$$average\ decomposition\% = \frac{decomposition\%_1 + decomposition\%_2 \ldots decomposition\%_{10}}{10}$$

$$percent\ error = \frac{|experimental\ value - theoretical\ value|}{theoratical\ value} \times 100$$

For nylon 6,10:

Average decomposition % = (0.40+14.83+4.57+3.45+0.60+0.60+1.81+1.60+2.60+0.59):10

= %3.10

Uncertainty= (99.80+2.50+8.50+11.56+66.47+66.47+22.02+24.80+15.18+66.47):10

=±38.38%

$$\text{Percent error} = \frac{|3.10 - 1.25|}{1.25} \times 100 = \pm 148.00\%$$

For biodegradable plastic:

Average decomposition % = (51.51+52.62+56.57+53.78+53.97+54.22+53.00+54.31+52.60+53.00):10

=%53.56

Uncertainty= (0.58+0.57+0.50+0.54+0.55+0.54+0.55+0.54+0.56+0.55):10

=±0.55%

$$\text{Percent error} = \frac{|53.56 - 60.00|}{60.00} \times 100 = \pm 10.73\%$$

CONCLUSION AND EVALUATION

I will now explain and examine the results of the experiment. This experiment was made in order to decide and examine if there was a plastic that can be decomposed under environmental conditions faster than normal plastics. As seen from my experimental results in part 7, there is a plastic that can be decomposed in environment better and faster than nylon and this plastic is called biodegradable plastic.

Basically, the experiment started by the synthesis of the plastics and after, the plastics were buried into the soil. After 180 days under the soil, plastics were collected by floating method and the final masses of the plastics were calculated and the data for this experiment was obtained by this way. 10 different trials were made for each plastic in order to obtain accurate data.

At the end of the experiment, it was calculated that averagely the biodegradable plastic dissolved by %53.56 ± 0.55% in 180 days while averagely the nylon 6,10 used in this experiment dissolved by %3.10 ± 38.38%. Although from this experiment it was seen that biodegradable plastics existed, the experimental values of decomposition percentage of plastics over 180 days were not accurate with the theoretical values of decomposition of these plastics. While the theoretical value of nylon 6,10 (1.25%) and my experimental value of the decomposition of nylon 6,10 (3.10%) for 180days were not accurate, the theoretical value (60%) and my experimental value of decomposition percentage (53.56%) of biodegradable plastic were close to each other, yet not the same.

From my results, it appears that the decomposition rate of the biodegradable plastic over 180 days was higher than the decomposition rate of nylon 6,10, which proves that biodegradable plastics can dissolve under environmental conditions better and faster than the normal plastics, which need centuries to dissolve completely under environmental conditions.

From the percent error of the nylon 6,10 and from the percent error of the biodegradable plastic, it is seen that in this experiment there were systematic errors as well as random errors:

8.1. Systematic Error and Improvements

The systematic errors can be caused by the method used in the experiment in order to measure the decomposition rate of the plastics over 180 days. According to ASTM, the percent decomposition of the biodegradable plastic was measured by a specific biodegradability experiment. In the experiment done by ASTM, the sample plastic and soil is kept under isolated conditions in a controlled temperature incubator. Inside this incubator, there would be the sample biodegradable plastic buried into the soil, humidifier in order to obtain moisture and a solenoid valve manifold. By the solenoid valve manifold, the carbon dioxide analyzer outside of the controlled incubator would detect and measure the rate of carbondioxide that the biodegradable plastic would produce while it is being decomposed; and according to ASTM, the 90% carbon in the biodegradable plastic should be converted in to carbondioxide and also 60% of the mass should be lost at the end of 180 days or less.

In my experiment I used the change in mass technique in order to detect the decomposition rate of the biodegradable plastic and the rate of decomposition of nylon 6,10 over 180 days; and from this experiment it is seen that this technique is not a hundred percent appropriate to calculate the decomposition rates of the plastics. So it can be said that the big amount of systematic error in this experiment is caused by the technique that I used in this experiment in order to detect and measure the decomposition rates of the plastics.

Beside the technique used in order to detect and measure the decomposition rate, the environmental conditions that I supplied for the plastics were not appropriate for the biodegradable plastic and nylon 6,10 to decompose accurately. For example, ASTM used a humidifier in order to keep the moisture controlled in the experiment; but in my experiment I did not supply any liquid context for the plastics that can directly affect the plastics' decomposition rate over 180 days. In order to solve the drought of the soil where the plastics were buried, same amount of water could be poured in to the every flowerpot every day for 180 days or drip irrigation system could be used in the experiment. By the drip irrigation system every flowerpot would get the same amount of water in every hour of each day for 180 days and by this way the drought of the flowerpots would be prevented.

Another systematic error was air conditions. ASTM kept air conditions controlled and for 180 days the temperature of the sample was controlled by the controlled temperature incubator; but in my experiment the temperature was not the same for 180 days although both of nylon 6,10 and the biodegradable plastic were exposed to the same different temperatures. But because these plastics were made up of different reagents and chemicals, their responses for different temperatures would differ and this would affect the decomposition rate of plastics directly. In order to solve this systematic error, an isolated system could be used, which would stop the energy and material flow, especially temperature change, in to the experiment and the temperature of the experiment could be controlled by controlled temperature indicator like the one ASTM used in its experiment.

One other systematic error was caused by the uncontrolled amount of microorganisms used in the samples. The microorganisms existed in the soil is one of the biggest factor that causes the plastics to decompose in soil, especially for the biodegradable plastics. Since in my experiment, the soil's microorganism and mineral rates were not measured and were not kept the same for 180 days, the rate of decomposition could decreased over the time interval, which causes the decomposition rate to not be accurate. In order to solve this systematic error, the qualities of the soil could be measured at the beginning of the experiment and according to these ratios of minerals and microorganisms could be kept constant by consolidation of microorganisms and minerals when any of these ratios decrease.

Another systematic error of the experiment was the time that the flowerpots were exposed to the sun light. Although all of the flowerpots that contained different plastics were kept in the same room, different amount of sun light reached to each flowerpot from the window. Since sunlight is one of the biggest factors that affect the decomposition rate, not controlling the sunlight rate that reached the flowerpots caused systematic errors. In order to solve this systematic error, an isolated system can be used in order to prevent sunlight from reaching the flowerpots.

Another systematic error was caused by the floating method used in order to collect the plastics after 180 days. There can be plastics buried in the soil and did not float on the water and this would directly affect the final masses of the plastics, which would then affect the decomposition rates of the plastics. By repeating the float method over and over for one flowerpot, this systematic error could be decreased to the minimum.

Also in order to solve all of these systematic errors mentioned above, a system like the ASTM used in its experiments can be used, which keeps water amount, temperature, microorganism rate, mineral rate and sunlight rate constant.

8.2. Random Error and Improvements

The random errors of the experiment can be caused by the wrong measurements and miscalculations made because of the wrong measurements. For example in the experiment, it was very challenging and hard to obtain exactly 5g of each plastic, so the initial mass of the plastics were close to each other yet not the same and this can cause random errors. Since the calculations of the experiment were made according to these wrong calculations, it affected the results of the experiment made. By measuring exactly 5g of the plastics for each trial this random error can be solved.

APPENDIX I

1. APPARATUS

For this investigation, two types of apparatus are required for two procedures outlined in the previous section.

For the synthesis of Nylon 6,10

- Beaker, 250mL (×2)
- Graduated cylinder, 100mL (×2)
- Scoopula (×2)
- Dropper (×1)
- Petri dish (×2)
- Stirring rod (×1)
- Forceps (×1)
- Magnetic stirrer bar (×2)
- Hot plate with magnetic stirrer(×1)
- Scale (×1)
- Stopwatch (×1)

For the synthesis of biodegradable plastic

- Beaker, 250mL (×1)
- Graduated cylinder, 100mL (×1)
- Scoopula (×1)
- Dropper (×2)
- Petri dish (×1)
- Magnetic stirrer bar (×1)
- Hot plate with magnetic stirrer(×1)
- Scale (×1)
- Stopwatch (×1)

For burying the plastics

- Flowerpot (×20)
- 30 cm ruler
- Topsoil
- Nylon 6,10 (50g)
- Biodegradable plastic (50g)

For obtaining the plastics after 180days

- Water (20L)
- Bucket (×1)
- Stirrer (×1)
- Stopwatch
- Electronic Scale

The apparatus listed above does not list quantities required for repeat readings.

2. REAGENTS/ CHEMICALS

For the synthesis of Nylon 6,10

- Diamine-1,6-hexane (50g)
- Sebacoyl Chloride (10mL)
- Sodium Carbonate (Na_2CO_3) (5g)
- n-hexane (1000mL)
- Distilled water (500mL)

For the synthesis of biodegradable plastic

- Starch (95g)
- Glycerol (50mL)
- Acetic acid (%5 concentration) (50mL)
- Distilled water (600mL)

APPENDIX II

Information on Reagents and Products

1. Diamine-1,6-hexane [11]

Molecular Formula: $C_6H_{16}N_2$

Molar Mass: 116.2 g/mol

Melting Point: 204-205°C

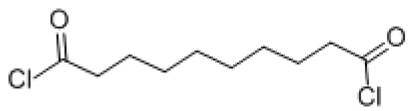
2. Sebacoyl Chloride [12]

Molecular Formula: $C_{10}H_{16}Cl_2O_2$

Molar Mass: 239.14g/mol

Melting Point: -2.5°C

Density: 1.21g/mL

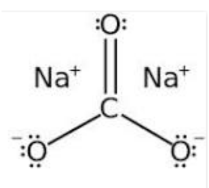


3. Sodium carbonate [13]

Molecular Formula: Na_2CO_3

Molar Mass: 105.99g/mol

Melting Point: 851°C



4. n-hexane [14]

Molecular Formula: C_6H_{14}

Molar Mass: 86.18g/mol

Melting Point: -95°C

Density: 0.692g/mL

5. Starch [15]

Molecular Formula: $(C_6H_{10}0_5)_n$

Melting Point: 256-258°C

Density: 1.5g/mL

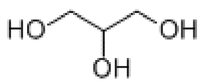
6. Glycerol [16]

Molecular Formula: $C_3H_8O_3$

Molar Mass: 92.09g/mol

Melting Point: 20°C

Density: 1.26g/mL



7. Hydrochloric acid [17]

Molecular Formula: HCl

Molar Mass:36.46g/mol

APPENDIX III

Photographs of the experiment

Fig5. Hexane-1,6-diamine measured for the synthesis of nylon 6,10

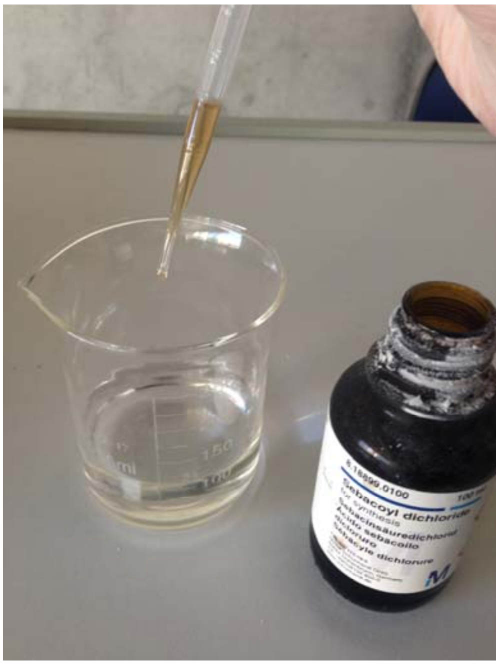


Fig7. Sebacoyl chloride poured into the hexane

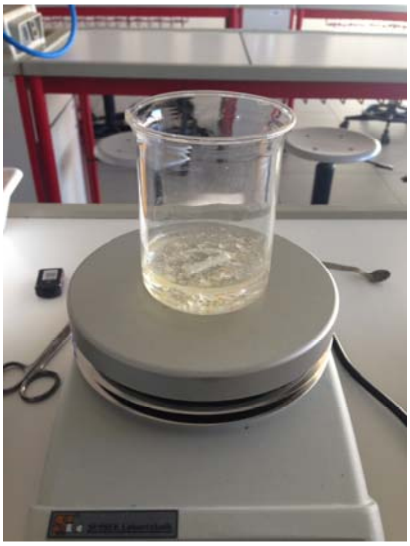


Fig6. Hexane-1,6-diamine dissolving in the water

F,g8: Layer between the hexane-1,6-diamine and sebacoyl chloride solutions

Fig9: Nylon 6,10 being extracted

Fig11: Starch being dissolved in the water

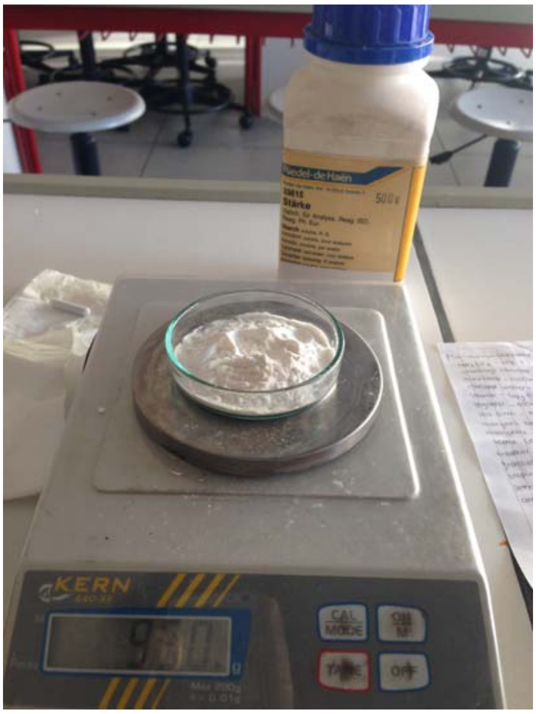


Fig10: Starch measured for the synthesis of biodegradable plastic

Fig12: The biodegradable plastics that has been produced

BIBLIOGRAPHY

[1] Craig Freudenrich, Ph.D. *How Plastic Works.* Web. 1 December 2013.

http:// science.howstuffworks.com/plastic.htm

[2] Jessica A. Knoblauch. *The environmental toll of plastics.* 1 December 2013.

http://www.environmentalhealthnews.org/ehs/news/dangers-of-plastic

[3] Connecticut Plastic. *Biodegradable Plastic.* 1 December 2013.

http://www.connecticutplastics.com/resources/connecticut-plastics-learning-center/biodegradable-plastics/

[4] EPI. *Standards.* 1 December 2013.

http://www.epi-global.com/en/tdpa-standards.php

[5] Chris E. Scott. *Nylon 6,10.* 1 December 2013.

http://www.polymerprocessing.com/polymers/PA610.html

[6] CHM130 Organic Lab. *Organic Polymers: The synthesis of Nylon.* 1 December 2013.

http://classes.kvcc.edu/chm130/ORGANIC-POLYMERS-updated.pdf

[7] 16 CFR 260.7b (1998).

[8] EstructuraProteinas. *Bioplastic from starch- home made*. Apr 8, 2013. Web. 2 December 2013.

http://www.youtube.com/watch?v=y1joh_t1thc&list=WLeK4I0ulaQxRqxlnoqXrkr7EBI0bkmtF9

[9] Deepak Prashar. Sanjay Kumar. *Synthesis, Characterization and Evaluation of Physical Properties of Biodegradable Composites from Corn Starch.* 2 December 2013.

http://www.phytojournal.com/vol1Issue2/Issue_july_2012/5.5.pdf

[10] Michael Bloch. *How long does X take to break down?* 2 December 2013

http://www.greenlivingtips.com/articles/waste-decomposition-rates.html

[11] Chemical Book. *1,6- hexandiamine.* 4 December 2013.

http://www.chemicalbook.com/ChemicalProductProperty_EN_CB7204696.htm

[12] Chemical Book. *Sebacoyl Chloride Basic Information.* 4 December 2013.

http://www.chemicalbook.com/ProductChemicalPropertiesCB3852835_EN.htm

[13] Chemical Book. *Sodium carbonate basic information.* 4 December 2013.

http://www.chemicalbook.com/ProductChemicalPropertiesCB9853672_EN.htm

[14] Chemical Book. *Hexane basic information.* 4 December 2013.

http://www.chemicalbook.com/ProductChemicalPropertiesCB1852811_EN.htm

[15] Chemical Book. *Starch basic information.* 4 December 2013.

http://www.chemicalbook.com/ProductChemicalPropertiesCB8349543_EN.htm

[16] Chemical Book. *Glycerol basic information.* 4 December 2013.

http://www.chemicalbook.com/ProductChemicalPropertiesCB5339206_EN.htm

[17] Chemical Book. *Hydrochloric acid basic information.* 4 December 2013.

http://www.chemicalbook.com/ProductChemicalPropertiesCB7421538_EN.htm