International Baccalaureate

Internal Assessment

Chemistry

Effect of heat exposure time on PLA

Research Question: How do different heating times at constant temperature (280℃) and at room pressure affect the amount of lactic acid released from PLA by titration with NaOH?

Word Count: 4000

Content

Introduction

Background knowledge:

The review entitled “Polymer Biodegradation and Biodegradable Polymers” was accepted in 2009. The review states that synthetic polymers are important in many industries, but have an undesirable impact on the environment and cause problems with waste accumulation. This research also describes the biodegradation processes of xenobiotics such as aromatic compounds, plastics. Since I was very interested in the article, I decided to write an experiment on this topic. At the same time, “Biodegradable polymers as biomaterials” accepted in 2007 and available on ScienceDirect article help me to detect the perfect biodegredable polymer for my experiment which is PLA (polylactic acid).

2.1 Biodegredable polymers

Degradable polymers are polymers that can be broken down into smaller molecules as a result of environmental conditions (heat, light, moisture, microorganisms, etc.) or chemical processes. These polymers can be biodegradable and break down into harmless compounds in nature over time. They are particularly used in environmentally friendly packaging, medical supplies and disposable products. There are many partially and fully biodegradable polymers and their blends in the world. These include naturally occurring polymers as well as poly(L-lactic acid), poly(ε-caprolactone), poly(3-hydroxybutarate), vegetable oil-based polyesters, epoxy and polyurethanes.Chemical degradation not only degrades polymer properties but also shortens the service life of the polymer by continuing the degradation chain. The most important factors causing chemical changes in polymer structure are light, heat, oxygen, humidity, moisture, ozone or atmospheric pollution and biological effects.

2.2 Types of degredation

- Thermal Degradation

- Oxidative Degradation

- Biodegradation

- Hydrolytic Degradation

- Photodegradation type degradation is mentioned.

Chemical degradation results in fading, brittleness, surface cracking, perspiration, crumbling (especially in foams), odor, surface acidity, surface aggregation, corrosion of metal parts.

2.3 Thermal degradation and Photodegradation

Thermal degradation: The energies of polymers increase under effects such as heating, sound, light and impact. The excess energy given to the polymer is met by the bending, stretching, vibration type movements of the chemical bonds and distributed within the polymer. When the polymer absorbs all the energy given to it by the aforementioned movements, chemical bond breaks are not observed in the polymer chains. If the energy supplied is excessive or rapidly charged to the polymer, the polymer cannot absorb all of the energy. The accumulation of

energy reaches a level that breaks chemical bonds in some regions and as a result, chemical bonds in polymer chains are broken.

Heat is one of the most common types of energy that polymers encounter. Most polymers are produced and shaped at certain temperatures and polymers are exposed to short-term heat in these initial stages. During their use, they encounter long-term heat energy, and thermal degradation of polymeric materials, especially those used outdoors and in hot environments, is inevitable.

Below are examples of reactions that may occur as a result of thermal degradation of polymers.

Chain fragmentation is one of the types of thermal degradation observed in polymers. Polymer chains are broken into smaller chains by breaking at a random place under the influence of heat and as a result, the molar mass of the polymer decreases.

When weaker bonds than the main chain bonds are present in the polymer, degradation proceeds through these bonds. For example, the carbon-chlorine bonds in PVC are weaker than the carbon-carbon bonds in the main chain and the polymer degrades releasing HCl.

- Intra-chain transfer is another reaction that can be observed during thermal degradation.

Some biodegradable polymers: Polylactic acid (PLA), Polyhydroxyalkanoates (PHAs), Polybutylene Succinate (PBS), Polyhydroxyurethanes (PHUs).

Polylactic acid (PLA) is a biodegradable as well as recyclable polyester made from renewable feedstock. Lactic acid as the raw material is produced by fermentation of glucose or sucrose and is refined to a high purity. Polylactic acid degrades abiotically by three mechanisms.

Hydrolysis: The ester groups of the main chain are broken down, thus reducing the molecular weight.

Thermal degradation: A complex phenomenon that leads to the appearance of lighter molecules and different compounds, such as linear and cyclic oligomers with different Mw and lactic acid.

Photodegradation: UV radiation causes degradation. At temperatures of 250 degrees Celsius or more, PLA starts to chemically deteriorate. The molecular makeup of PLA disintegrates during this process. Lactic acid can be released during PLA degradation when the polymer chains break down into smaller molecules of lactic acid monomers. When PLA is heated, it often breaks down into compounds with carboxyl groups and may produce carbon dioxide gas during thisprocess.

2.4 The first thing the experiment tries to examine

This experiment was carried out by looking at the effect of UV exposure time on the degradation of the polymer. However, in this experiment I investigated the effect of different heating times on the degradation of the polymer because in the experiment with UV light, degradation can be carried out using UV-C (100-280 nm) or UV-B (280-315) lamps. UV-A (315-400 nm) lamps are used to initiate photochemical reactions rather than polymer degradation. At the same time, the UV lamp experiment requires very long hours of exposure to UV light for observable

degradation. I did not want to be exposed to this light for long periods of time, I performed the experiment through thermal degradation.

2.5 3D Printer

I printed the PLA samples I used in the experiment using a 3D printer. Three-dimensional printing is the process of producing a 3D-designed virtual object from materials such as polymers, composites, resins by heat or chemical treatment. The devices that perform this process are called three-dimensional printers. Prints can be made with the use of many types of raw materials. The most widely used raw materials for normal users are hard plastics called PLA and ABS. The process of printing on 3D printers first starts with modeling the design. Sketchup, a 3D design program, can be used for modeling. When modeling, the width, height and depth of the PLA you want to remove are also determined. Objects scanned with a 3D scanner are exported in the '.stl' extension. The 3D printer detects the file in the '.stl' extension and performs the printing process. Before starting the printing process, the head area called 'nozzle' at the end of the printer must reach a certain temperature. Because the 3D printing process takes place by laying the melting filament layer by layer and on top of each other. In order for the filament to spread properly, it must melt at a high temperature as it comes out of the head point. As soon as the filament melts from the head point and spreads on the surface, it freezes and takes solid form. After all layers are completed, the model is completely ready in solid form.

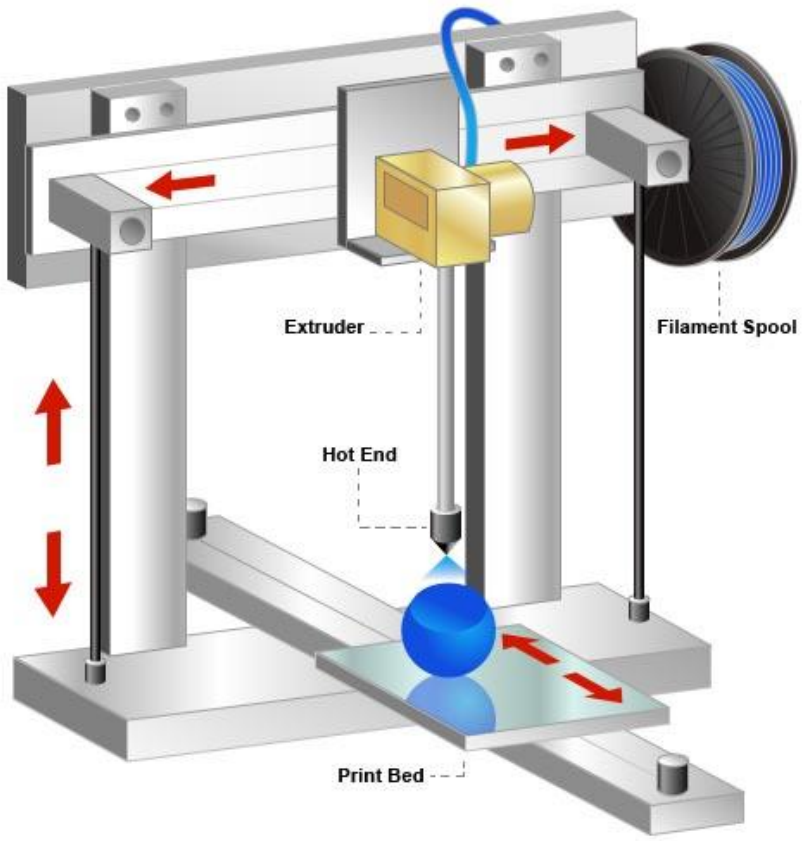


Figure 1: 3D printer and parts

2.6 FT-IR Machine

The FT-IR machine sends infrared rays into a sample. Molecules absorb the light and the chemical bonds in their structure vibrate at specific wavelengths. Since each chemical bond has a different frequency, it creates a fingerprint unique to the chemical structure of the substance. This instrument analyzes the structure of polymers, detects thermal, oxidative or chemical degradation and examines the types of bonds in the sample. In this research it was used to analyze chemical bond degradation in polylactic acid films.

To use this instrument, PLA samples in solid form are first compressed between potassium bromide tablets. The compressed sample is then placed in a special compartment of the device. The device passes infrared light through the sample and records the wavelengths transmitted. The recorded signals are analyzed by Fourir transform and a spectrum is generated. The spectrum is compared with spectral data of known chemical groups. The peaks on the spectrum indicate specific chemical bonds in the sample. In this experiment, the breakage of ester groups during the degradation of PLA is observed as a reduction and disappearance of certain wave peaks.

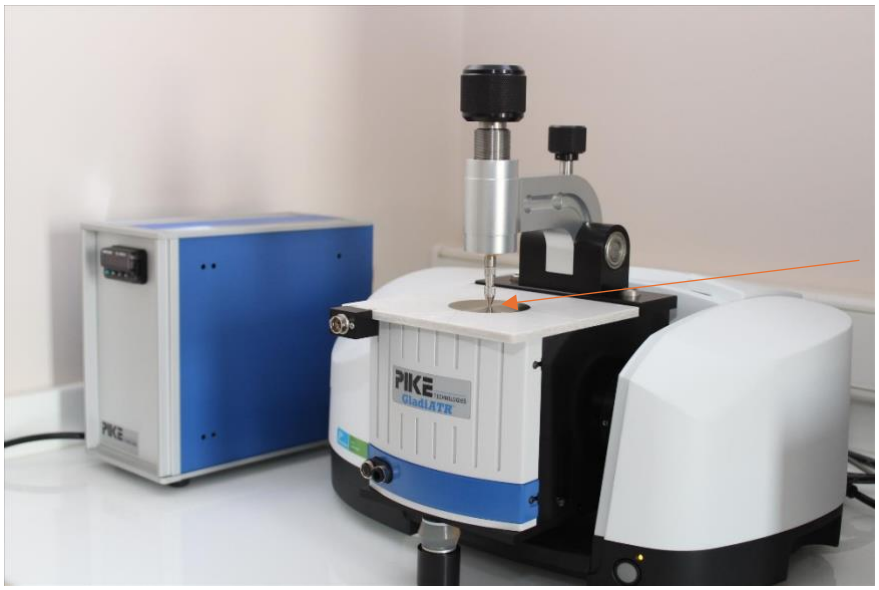


Figure 2: The FT-IR machine used. The arrow indicates where the sample was placed.

Hypothesis: As the heat exposure time increases, the lactic acid output from the degradable polymer (polylactic acid) increases based on thermal degradation mechanism, resulting in a decrease in the volume of sodium hydroxide used for titration of the polymer.

5.1. Materials

5.1.1 chemicals and solutions	**Volume / Mass/Quantity**
Biodegradable polymer (PLA)	25 pieces (seperated into groups of 5)
Titrant solvent(cloroform)	30 mL for each of the PLA groups to be dissolved in
Titration Solution (NaOH)	1 liters (0.965 $moldm^{-3}$)
Indicator(phenolphatelin)	3 drops
Distilled water	1 liters

5.1.2 Apparatures- Equipments	Uncertainty	Quantity
Hot plate	N/A	1
3D Printer	N/A	1
Timer	$\pm$ 0.01	1
Precision scale	$\pm$ 0.01	1
Burette	$\pm$ 0.05	1
Stopcock	N/A	1
Buret clamp	N/A	1
Retort stand	N/A	1
Funnel	N/A	1
Pipette filler	N/A	5
Pipette	$\pm$ 0.01	5
Erlenmeyer flask	± 0.5	5
Beakers	$\pm$ 0.5	5
Glassware	$\pm$ 0.5	5
Safety goggles	N/A	1
Lab coat	N/A	1

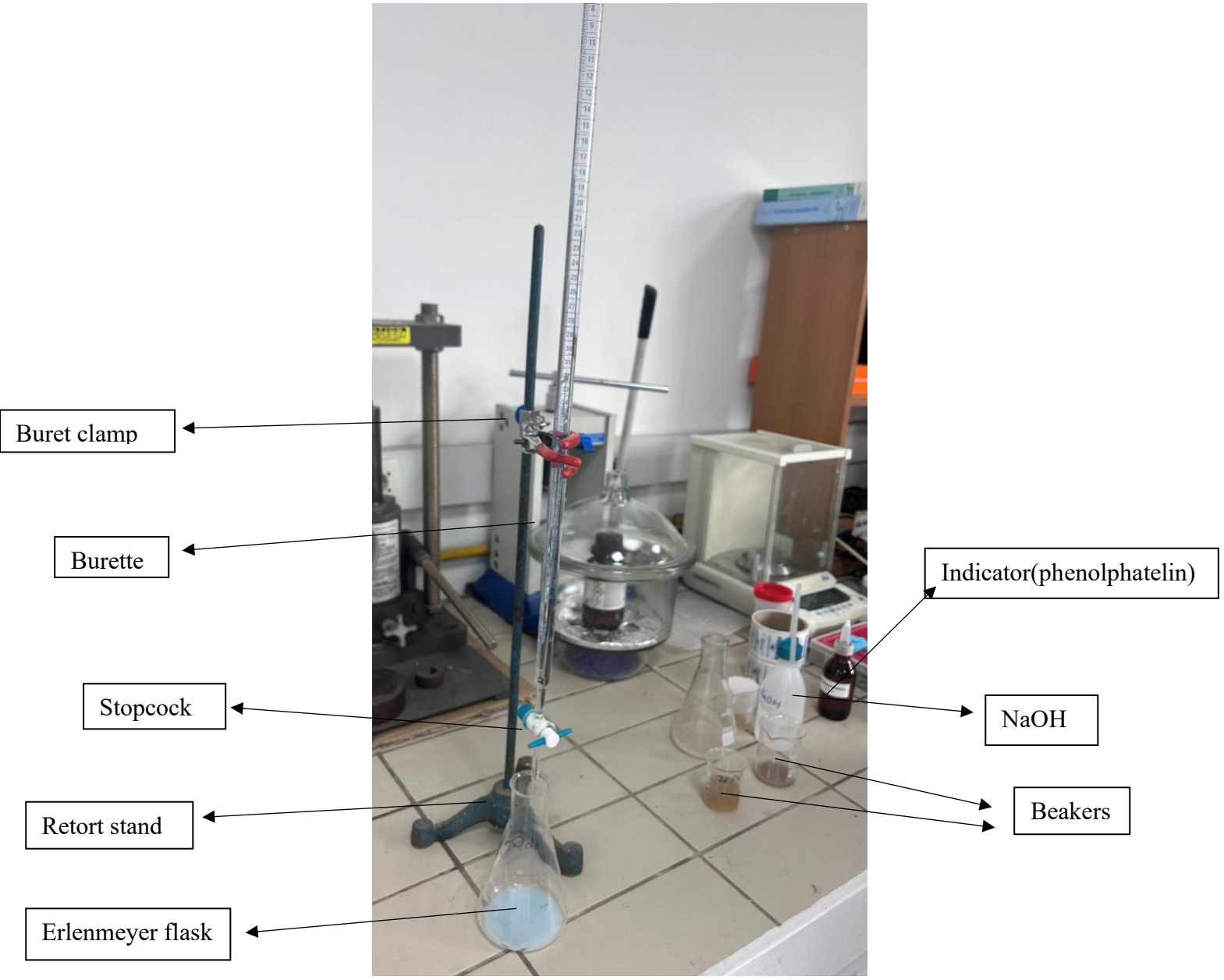


Figure 1: Titration Setup

5.2 Procedure

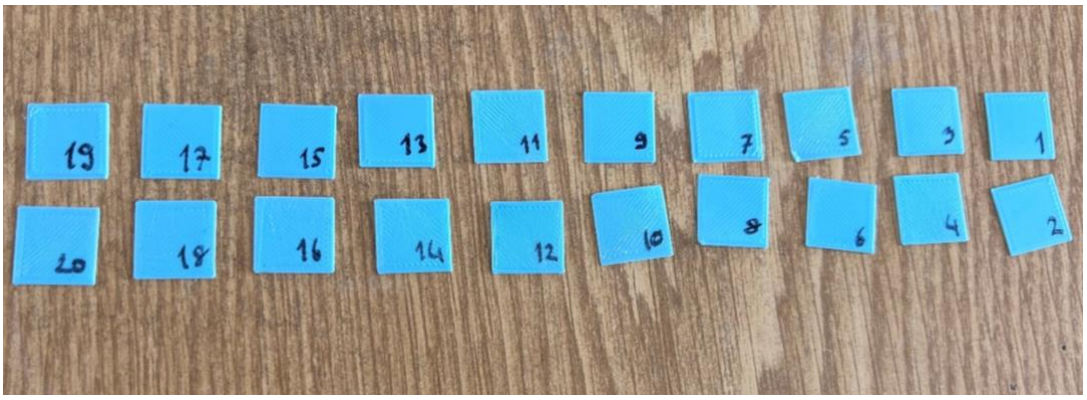
1. Print 25 pieces of polylactic acid film 1mm long on all 4 sides and 0.5mm thick on a 3D printer.
2. Investigate the chemical properties of PLA films by FT-IR.
3. List the samples from 1 to 25 and write their numbers on them.
4. Measure the weight of each film with precision scale.
5. Divide the 25 samples into 5 groups of five according to the measurements made (the groups are divided by aiming for the sum of the grams to be the same or as close as possible).
6. Place the polymer samples under 280 degree on hot plate.
7. The first group of five will be left unheated.
8. The second group of five will be heated for ten minutes.
9. The third group of five will be heated for twenty minutes.
10. The fourth group of five will be heated for thirty minutes.
11. The fifth group of five will be heated for fourty minutes.

12. Set up the titration equipment and calibrate as necessary.
13. Prepare polymer samples that have never seen heat and have been heated for a certain time (10 min, 20 min, 30 min, 40 min) for titration by dissolving them in 30 mL chloroform in different 5 beakers.
14. Conduct titrations for each polymer sample using the titrant solution.
15. Monitor pH any other relevant parameters during the titration process.

Titration set up:

1. Taking a clean burette, first distilled water, then NaOH to be used in the titration solution is made ready for use.
2. The buret is attached to the buret clamp. Make sure it is securely fastened to prevent movement.
3. With the help of a funnel is filled to the zero mark with NaOH solution of 0.965 $moldm^{-3}$ concentration.
4. Using a pipette transfer the polymer samples that disolved with cloroform to a clean erlenmeyer flask.
5. Add 3 drops of phenolphatelin to the analyte solution in the flask. Indicator uses for observe the color change.
6. Place the erlenmeyer flask directly under the burette tip.
7. The NaOH solution is added dropwise into the flask and the flask is shaken continuously.
8. Endpoint when approached, the addition of base is slowed down.
9. Continue the titration process until a pink color is obtained.
10. The point of permanent pink color is the endpoint.
11. Volume of base spent read from the buret and noted.
12. Repeat this process five times each.

Figure 2 : 20 of the numbered PLA samples



5.3 Variables

Table 2. Independent vs Dependent Variables

Variable	What Variable?	Why?
Independent	exposure time to heat	I changed duration of heat applied to the biodegradable polymer. 0, 10 minute, 20 minute, 30 minute, 40 minute
Dependent	Molar concentration of lactic acid	When I increased the heat time, further degradation of the biodegradable polymer occurred, which increased the release of lactic acid

Table 3. Controlled Variables

What variable?	How ?	What variable?	How ?
Heat source	It should be used in the same environment without changing the heat source during the whole experiment	**Temperature**	Conduct all experiments in a temperature-controlled environment conduct the experiment in a lab at 25 degrees Celsius.
Concentration of titrant	The concentration of NaOH which is 0.965 $moldm^{-3}$ in the burette must be constant for each experiment.	**Scale**	Use the same scale for all measurements and calibrate the instrument before use.
Beakers , Erlenmeyer flask	The equipment used must be the same every time. This ensures that the correct values are maintained.	**Volume of analyte solution**	The volume of the analyzed solution 10 cm^3 must be measured accurately and be the same volume for each trial.
Mixing speed	The stirring speed must be consistent during titration. Changes in stirring speed can affect the color appearance.	**Type and volume of indicator**	The indicator used must be the same each trial (phenolphatelin) an in the same amount (3 drop)
Biodegradable polymer samples	Ensure that the polymer samples are exposed to the same surface area and size. For this you need to make all the samples the same size on the 3D printer.		

5.4 Risk Assessment and Environmental Considerations

Hazard	Risk	How to Minimize	Emergency Actions
Titrant solvent (cloroform)	This substance may be irritating and caustic or even harmful to the eyes if inhaled or swallowed or contacted.	Store used chemical in properly labeled containers. Keep spill kits around in case of spills.	If the chemical comes into contact with your skin or eyes, rinse with plenty of water.
Analyzed solution (PLA dissolved in cloroform)	PLA is a acid and when heated, lactic acid is produced, which causes respiratory problems. It causes irritation in contact with eyes and skin.	When this chemical is heated during the experiment, a protective mask should be worn and the fume hood should be switched on, and lactic acid should not be inhaled too much. When dissolving PLA with cloroform, stirring should be gentle and care should be taken not to splash. Lab coat and goggles should be worn to protect eyes and skin.	After inhalation, move the exposed person to fresh air. If discomfort or irritation persists, seek medical advice If breathing is difficult, give oxygen. After contact with eyes or skin, rinse irritated area gently with clean water.
Titrant solution (NaOH)	NaOH is a strong base. It may cause skin burns and eye irritation if splashed into the eyes or skin during the experiment.	When using this chemical, wear safety googles to prevent it from getting into the eyes, and wear a lab coat and gloves to avoid contact with the skin. Be careful not to spill NaOH when pouring it into the burette.	If skin contact has occurred, immediately remove spilled clothing and shoes and wash affected area with soap and water. If splashed into eyes, rinse gently with water for 15-20 minutes. Seek medical attention immediately.

Glass Materials	Beakers of glass materials and other fragile equipment can splash into the eyes or cause cuts on your body.	Wearing gloves, goggles and lab coat.	If you cut yourself, rinse the wound with water, apply antiseptic and cover with a bandage. Get medical help for a serious cut.
Heat Source	Because the polymer is heated at 280 degrees, this is a very high temperature and it can burn our skin and leave deep damage.	Wearing insulating materials and hold the polymers to the heat with similarly insulating materials	If the heat source comes into contact with our skin and burns it, cold should be applied and if there is an open wound, antiseptic should be applied and bandaged.

As the substance cloroform, is harmful and degrading to natural life and living organisms; a proper disposal of this substance will be done. It will be managed as “Chemical Waste” to ensure the minimization of the contamination cloroform, may cause to the environment.

Data Collection and Analysis

Table 5. Mass of each of the 25 polymers (grams) ±0.001

1-0.129	2-0.116	3-0.108	4-0.128	5-0.133
6-0.131	7-0.119	8-0.128	9-0.116	10-0.131
11-0.117	12-0.130	13-0.121	14-0.127	15-0.120
16-0.123	17-0.128	18-0.112	19-0.110	20-0.130
21-0.129	22-0.122	23-0.127	24-0.119	25-0.118

Figure 3: PLA sample weighed on a precision scale

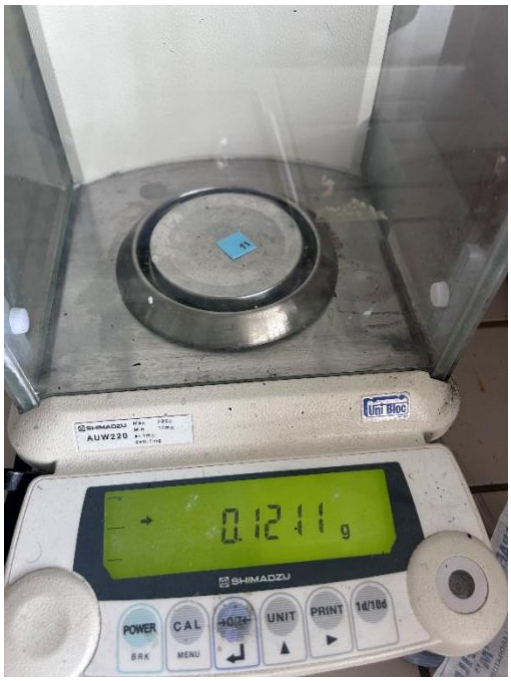


Table 6.1. Raw Data

	Volume of Sodium Hydroxide(NaOH) Required / $cm^3(\pm 0.05\ cm^3)$									
Trials	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
time to heat(min)	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
0	7.10	9.50	7.10	9.20	7.10	9.60	7.10	9.40	7.10	9.10
10	9.50	10.70	9.20	10.60	9.60	11.10	9.40	10.60	9.10	10.20
20	10.70	11.50	10.60	11.10	11.10	12.10	10.60	11.30	10.20	11.10
30	11.50	12.00	11.10	11.80	12.10	12.70	11.30	11.70	11.10	11.50
40	12.00	12.20	11.80	12.20	12.70	13.00	11.70	11.90	11.40	11.70

Figure 4: PLA samples heat treated before titration and dissolved in cloroform

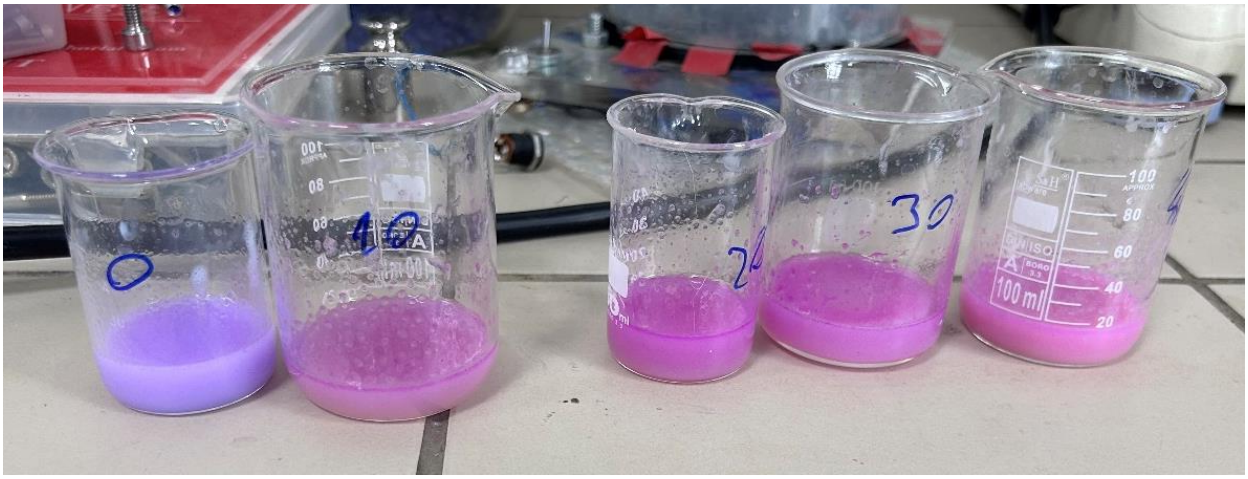


Figure 5: PLA samples heat treated after titration and dissolved in cloroform

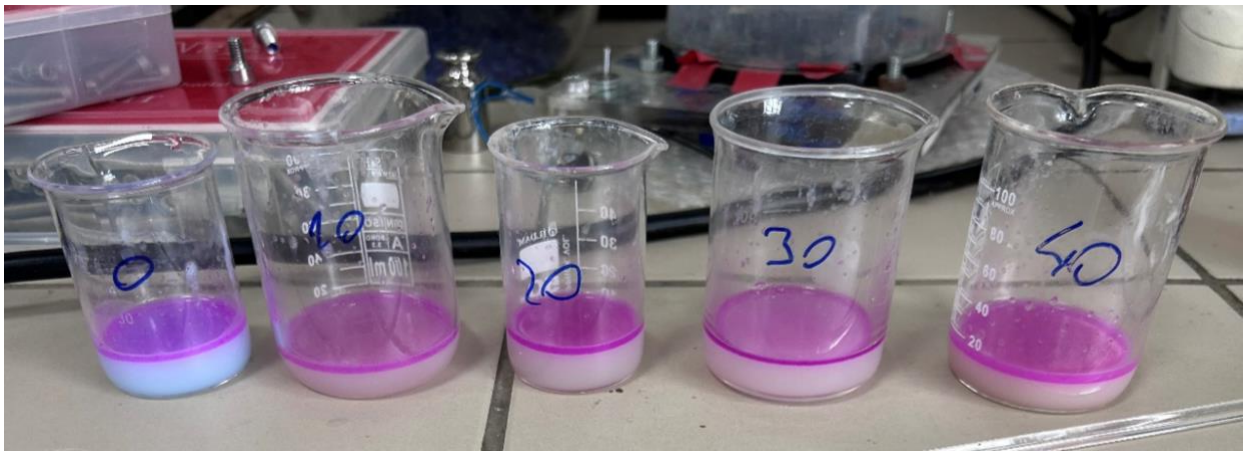


Figure 6: PLA samples in figure 5 after remained untouched

6.2 Processed Data

To calculate the volume of sodium hydroxide used in each trial after incubation, the initial reading was subtracted from the final reading as shown in the example calculation below:

1. Volume of titre = Final Reading − Initial Reading
   Volume of sodium hydroxide used = 9.50 ± 0.05 − 7.10 ± 0.05 = 2.40 ± 0.10

Table 7: Volume of Sodium Hydroxide Used

Time(minute)	**Volume of Sodium Hydroxide That Reacted/cm^3($\pm$0.10)**				
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
Without heating	2.40	2.10	2.50	2.30	2.00
Heated for 10 minutes	1.20	1.40	1.50	1.20	1.10
Heated for 20 minutes	0.80	0.50	1.00	0.70	0.90
Heated for 30 minutes	0.50	0.70	0.60	0.40	0.40
Heated for 40 minutes	0.20	0.40	0.30	0.20	0.30

6.3 Calculation of Molarity

Titration formula: $M_A * V_A = M_B * V_B$

2. M_A= Concentration of acid
3. V_A=Volume of acid
4. M_B= Concentration of base
5. V_B=Volume of base
6. The process is done by placing the value obtained as a result of the measurement into the equation.
7. $0.965 \times 2.40 = 10.00 \times M$
   2.316=10.00 × M

M=0.232 $moldm^{-3}$

8. Calculate the percentage uncertainties of each trial for each concentration using the formula;

Example Calculation for Percentage Uncertainty of Trial 1 = $\frac{(0.10)}{(2.40)} \times 100 = 4\%$

$$\frac{0.05}{10.00} \times 100 = 0.50\%$$

0.50% + 4% = 5%

9. Calculate the average of each trial for each volume using the formula;

$$\frac{Sum\ of\ the\ values\ of\ 5\ trials}{5}$$

10. Example Calculation of without heating = $\frac{0.232+0.203+0.241+0.222+0.193}{5} = 0.218$
11. Calculate the average percentage uncertainty of each trial for each volume using the formula;

$$\frac{max-min}{2\sqrt{n}}$$

12. Example Calculation of without heating = $\frac{0.241-0.193}{2\sqrt{5}} = 0.011$

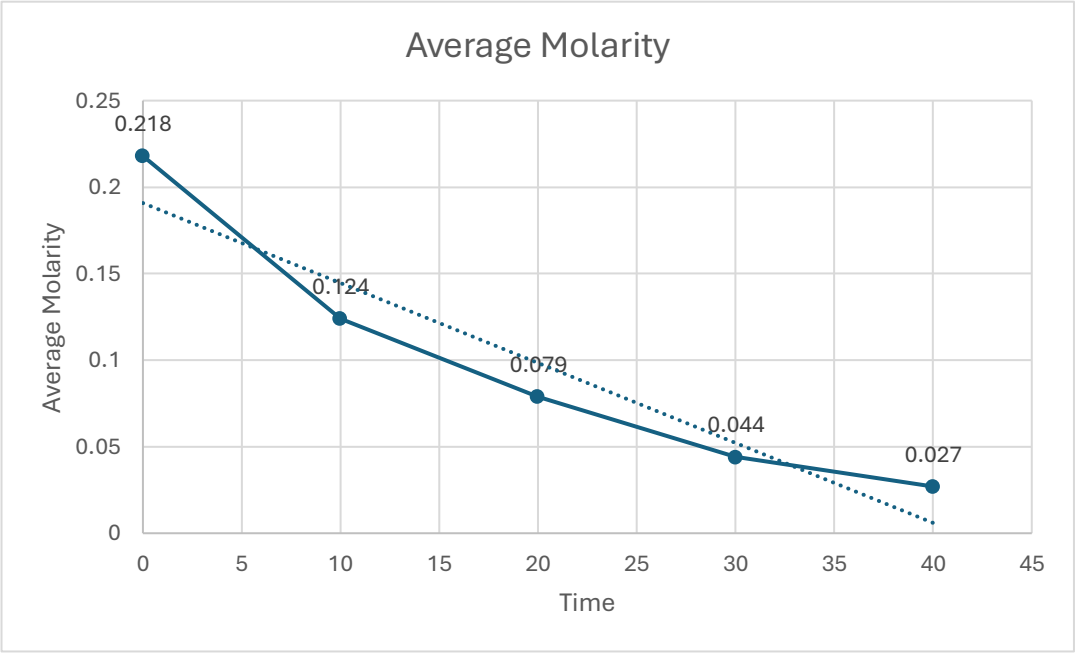
0.218 ± 0.011

$\frac{0.011}{0.218} \times 100 = 5\%$

6.4 Table 7: Proceed Data

Time(minute)	Molarity of Lactic Acid That Reacted/$cm^3(\pm 0.10)$					Average Molarity	Average Percentage Uncertainty
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
Without heating	0.232 ±5%	0.203 ±5%	0.241 ±5%	0.222 ±5%	0.193 ±6 %	0.218	± 5 %
Heated for 10 minutes	0.116 ±9 %	0.135 ±8%	0.145±7 %	0.116 ±9%	0.106 ±10 %	0.124	± 24 %
Heated for 20 minutes	0.077 ±13%	0.068 ±15%	0.097±11 %	0.068 ±15 %	0.087 ±12 %	0.079	± 8%
Heated for 30 minutes	0.048 ±21%	0.048 ±21%	0.058 ±17 %	0.039 ±26 %	0.041 ±23 %	0.044	± 9%
Heated for 40 minutes	0.019 ±51%	0.039 ±26%	0.029 ±34 %	0.019 ±51 %	0.029 ±33 %	0.027	± 15 %

Table 8: Line Graph



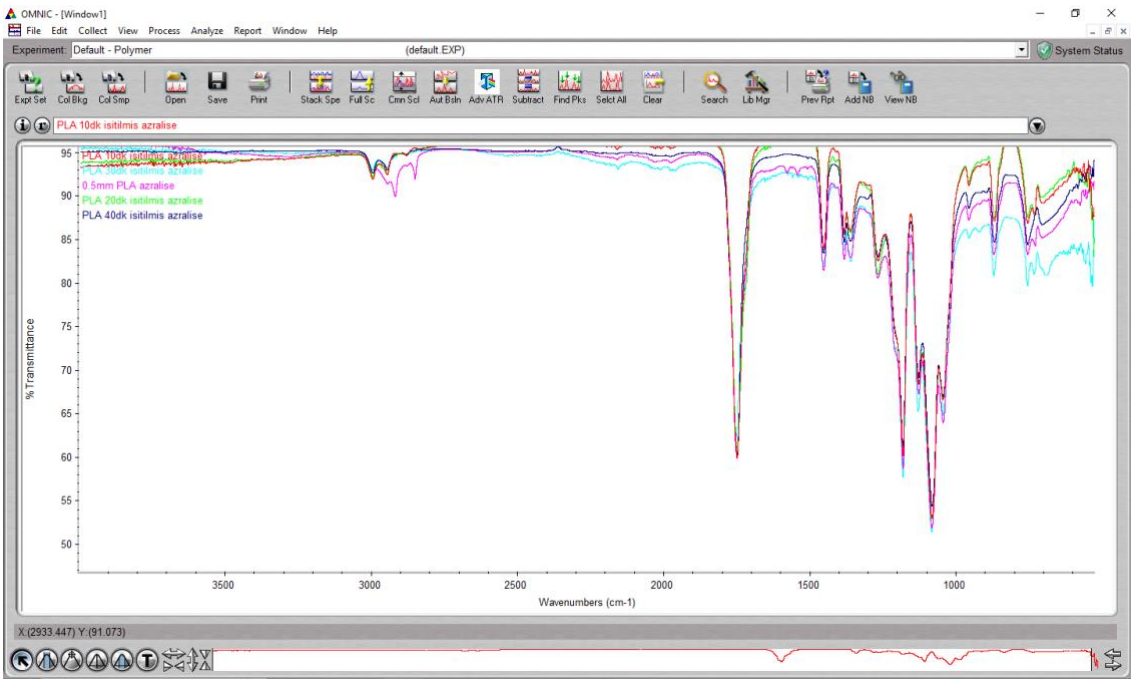


Figure 7: Decays seen in FT-IR after the experiment was completed. Spectra of samples heated for different minutes are superimposed. Peaks indicate chemical decomposition.

Heating time	Change in peaks
0 minute	PLA structure intact, ester (C=O), C-O strong peaks clear.
10 minute	Slight deterioration and decrease in C=O and C-O peaks.
20 minute	Moderate deterioration, C=O and C-O marked attenuation, OH group started to appear.
30 minute	Advanced degradation, C=O and C-O are very weak, OH and COOH groups are clear.
40 minute	Severe degradation, C=O and C-O almost absent, OH and COOH groups predominate, peaks of new degradation products.

Conclusion

The aim of the experiment is to find out how the duration of heat exposure affects the titration of biodegradable polymers. As I stated in my hypothesis, if the PLA polymer is heated at the same temperature for 0 minutes, 10 minutes, 20 minutes, 30 minutes, 40 minutes, the amount of lactic acid produced increases, which reduces the molarity of sodium hydroxide used for

titration. The results of the experiment proved that the hypothesis was correct. When sodium hydroxide and unheated PLA are combined, the average molarity is 0.218 $moldm^{-3}$. This shows the stability of the polymer. It can be seen that the molarity decreases to 0.124 $moldm^{-3}$ after 10 minutes of heating, indicating that the polymer is degraded. After heating for 20, 30, 40 minutes, the molarity was 0.079 $moldm^{-3}$, 0.044 $moldm^{-3}$ and 0.027 $moldm^{-3}$ respectively. This suggests that longer exposure to heat causes more degradation and reduces the polymer's ability to react with sodium hydroxide in titration. Since my experiment was consistent with my hypothesis, we can conclude with certainty that the polymer degrades more as the heating time increases. Also, as seen in the graph in table 8, the decrease in the molarity of lactic acid was directly proportional to the increase in heating time because, as I have mentioned many times, as the heating time increases, the degradation increases, which causes the release of lactic acid in PLA. With the release of lactic acid, the concentration decreases, which allows us to see that the results of the titration with sodium hydroxide using the formula ($M_A * V_A = M_B * V_B$) show that the molarity decreases in direct proportion. After the PLAs were warmed up, we put the samples into the FT-IR instrument and the results are shown in figure 7. Since the degradation process is a long process, the peak points and the properties of the heated and unheated sample are not very clear unless the device used is looked at in detail. However, if we look at the peaks between unheated and 40 minutes heated PLA, there is a noticeable difference. The unheated PLA is shown by the pink line and the PLA sample heated for 40 minutes is shown by the dark blue line. This helped us to prove our hypothesis not only experimentally but also systematically. The low percentage of uncertainty in the data proves that the results are largely reliable. The decrease in molarity with increasing heating time confirmed that heat exposure time significantly affects the chemical properties of biodegradable polymers, making them less reactive during titration. In other words, this study concluded that the effective heat exposure time (280 degrees) is an important factor affecting the chemical reactivity of biodegradable polymers.

Evaluation:

Limitations that small errors affecting the experiment affect the results of the experiment. Minimizing these errors can improve the results in subsequent experiments. These consist of;

Table 9. Weaknesses of the exploration

Weakness	Significance	Improvements and extensions
inconsistency in heating distribution	Uneven heating can cause differences in the breakdown of the polymer.	A thermostat-controlled water bath can be used to keep the heat distribution more consistent.
Keeping heating times short	Using only specific time intervals such as 0,10,20,30,40 minutes may not show distortions accurately.	For longer than 40 minutes, it is recommended to repeat the experiment with measurements.
Human error during titration	When the end point of the titration is detected by eye, it cannot be measured precisely enough and affects the results of the experiment.	Technology can be used in titration, such as an automatic titration device
Failure to control environmental factors	The ambient temperature, the amount of humidity in the environment, the amount of oxygen in the area of the experiment can affect the reaction of the polymer.	Experimentation under controlled laboratory conditions is recommended.
Purity of titration chemicals	The purity of the chemicals used can affect the results and lead to loss of precision.	The accuracy of the experiment can be improved by using chemicals of higher purity.
Sample cooling time after heating	Cooling of the samples at different rates may affect the molecular changes because the experiment measures the effect of the heating time.	The samples should be allowed to cool under controlled conditions for an equal time.
Small sample size	Only groups with 5 different heating times and 5 samples each were used.	Statistical reliability can be increased by using more samples.
Solvent (chlororform) volatility	Since chloroform is a volatile substance, it can evaporate during the experiment and change the solution concentration.	Work can be done in closed containers to reduce solvent evaporation.
Possibility that polymers may not dissolve completely	The incomplete solubilization of PLA in the solvent results in a non-homogeneous solution during titration.	Dissolution time can be extended or post-dissolution filtration can be performed.
Unknown chemical history of PLA samples	Differences in the production conditions or previous environmental exposure of the PLA samples used. This can affect their shearing behavior.	Preferring materials from the same supplier and with known production history for each sample.

Individual differences in the perception of visual color change	The pink color transformation in the flicker may be based on perceptions that vary from person to person.	More objective measurements can be made using color sensors or spectrophotometers.
Ignoring the possibility of catalytic effect	Some side reactions or catalytic effects on surfaces may occur during heat treatment.	Possible catalytic effects can be observed by conducting tests with different container materials (glass, Teflon).

Table 10. Strengths of the exploration

Strength	Significance	Strength	Significance
Controlled variables	Keeping variables other than those that need to be changed in the study constant increases the reliability of the experiment and reduces errors	**Low percentage error**	Indicates that the measurements are accurate.
Repetition of experiment	Repeating experiments increases the reliability of the results and reduces random errors.	**Analyzing the mechanism of deterioration.**	Other chemical changes of the substance were analyzed using the FT-IR technique.
Collection of quantitative data	Collecting and graphing data that clearly shows the decrease in molarity as the heating time increases.	**Standardization of sample sizes**	Keeping the size and shape of the polymer samples constant ensures that the heat exposure rates are the same.
Working on a current and environmentally friendly material such as PLA	Investigating the chemical resistance of environmentally friendly materials, such as biobased plimers, can make important contributions to sustainability.	**Carrying out the work with environmental awareness**	Proper waste management to prevent harmful substances such as chloroform from harming the environment.
Providing data diversity by using various heating times	The response of the polymer to heat was comprehensively evaluated by testing different exposure times.	**Attention to safety precautions**	Use appropriate personal protective equipment, taking into account that chemicals can be dangerous.

Analytical processing of data	Quantitative analyses such as average molarities and percentage uncertainties were performed to provide a scientific basis for the data.	**The study is intended for industrial applications**	Investigating the heat resistance of polymer can provide useful information in areas such as materials engineering and packaging industry.
Results are consistent with the hypothesis	The fact that the findings support the hypothesis shows the accuracy of the experimental design.	**The laboratory equipment used in the study is simple and accessible**	It is highly reproducible because it is performed with common basic laboratory equipment instead of complex instruments.

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