

UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

The Compostability of Biodegradable Polymer Products

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CHBE 496

April 2010

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The Compostability of Biodegradable Polymer Products

University of British Columbia
Chemical and Biological Engineering
CHBE 496 Undergraduate Thesis

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Submitted: April 15th, 2010

Abstract

The compostability of a few biodegradable polymer (BDP) products were investigated through two sets of tests. The first set of tests is laboratory-scale tests that were conducted in Dr. Anthony Lau's laboratory in the department of Chemical and Biological Engineering. The second set of tests is pilot-scale tests which were conducted in the UBC in-vessel composter. The polymers studied includes: Biodegradable Solutions International (BSI) Polylacticacid (PLA), Biodegradable Food Services (BFS) PLA, BiobagTM biodegradable plastic bags, RalstonTM oxo-biodegradable plastic bags, and PapermateTM pen casings.

Qualitative analysis of the composting results showed that apart from BiobagTM biodegradable plastic bags, the other polymer products showed little or no signs of degradation. A comparison between BFS polymer and BSI polymer showed that BFS degrades faster since discoloration was observed after 2 weeks on composting in the laboratory-scale tests compared to no physical changes with the BSI polymer. Analysis of the BSI polymer retrieved from the pilot-scale tests however, showed changes in tensile strength, which might indicate degradation of the polymer through hydrolysis.

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Additionally, I would also like to thank Seunggun Won, Dr Anthony Lau's PhD student which provided much assistance in the lab with regard to setting up the apparatus, and constant monitoring of the reactor temperatures.

Finally, I would like to thank Christian Beaudrie, Outreach Coordinator; Liska Richer, SEEDS Program Coordinator; and Mike `The Composter` for providing information and assistance with the pilot-scale side of this project in the UBC in-vessel composter.

April 15th, 2010
Dr. Peter Englezos, Head
Department of Chemical and Biological Engineering
The University of British Columbia
2360 East Mall
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V6T 1Z3

Dear Dr. Peter Englezos:

Enclosed with this letter is my CHBE 496 Undergraduate Thesis Report entitled *The Compostability of Biodegradable Polymer Products*. The research conducted was completed under the supervision of Dr. Anthony Lau.

The use of biodegradable polymer around the UBC campus requires a second look at its viability. The UBC in-vessel composter receives a number of Biodegradable Solutions International (BSI) biodegradable cutleries every day to be degraded into compost. However, these polymers were not found to degrade after coming out of the composter. My research was conducted on the compostability of these cutleries along with a few other biodegradable polymers including an alternative biodegradable cutlery from Biodegradable Food Services (BFS) to potentially replace the existing one.

According to results obtained from the research, signs of degradation were observed with both biodegradable cutleries; however the product obtained from BFS were found to degrade faster than those obtained from BSI. Further studies are required to determine the amount of time required for complete degradation of each polymer. Also included in this report are recommendations on potential future works that could be conducted.

Please contact me with any further inquiries regarding this report at [REDACTED] or [REDACTED].

Sincerely,

Richard Chen

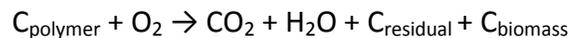
Enclosure: CHBE 496 Undergraduate Thesis Report

1.0 Background Information

1.1 Biodegradable Polymers

Polymers are macromolecules made of smaller building blocks called monomers. These molecules come in various forms such as DNA, proteins, cellulose, and of course plastic. Plastics are polymers that have some degree of flexibility yet a good strength that allow for applications in everyday uses. Most plastic products are produced by polymerization of monomers to create products with desired thermal and physical characteristics.

Biodegradable polymers (BDP) are polymers that can be broken down into its substrates and consumed by micro-organisms to be broken down into water and carbon dioxide. The chemical reaction for aerobic biodegradation of polymers is as follows:



As can be seen in the above reaction, the polymer which acts as substrate, is broken down and consumed along with oxygen to produce water, carbon dioxide, polymer residues, and also produces cells. Enzymes released by microbes in the composting environment along with the assistance of water, help the breakdown of large polymer chains into smaller pieces which allows for bacteria to consume them much like a glucose molecule.

Biodegradable polymers are categorized into two general groups, natural and synthetic. Natural polymers are those that exist naturally as their polymer form such as cellulose, silk, wool, and polyhydroxyalkanoates (PHA). On the other hand, synthetic polymers are those that come from monomers and synthesized into the polymeric form such as polylacticacid (PLA) and polycaprolactone (PCL). Generally, the biodegradability of these polymers comes from the

functional groups of the monomer. For example, the chemical structure of PLA and PCL can be seen in figure 1.

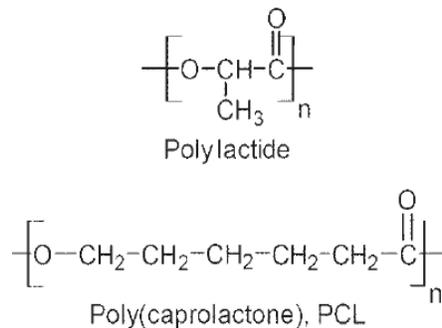


Figure 1. Chemical Structure of PLA and PCL

The ester groups in both polymers allow water to better hydrolyze the polymer chains and increase the flexibility of the polymers so that they can better fit into enzyme active sites.

To determine whether these polymers can be labelled as biodegradable in their respectable markets, testing methods have been created to determine the rate of biodegradation, toxicology, and various other parameters. In North America, the organization to create these standards are the American Society for Testing and Materials (ASTM), and the guidelines to determine the compostability of biodegradable polymers are ASTM 5338-03 “Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions” and ASTM D6400-04 “Standard Specification for Compostable Plastics.

1.2 Composting

Composting is a managed process of biological decomposition of organic waste, which also includes a high temperature phase. Micro-organisms that assist in this breakdown include

various species of bacteria, fungi and actinomycetes. In the composting process there are three phases:

1. Mesophilic phase – This phase occurs during the beginning of the composting process with mesophilic bacteria and fungi as the main organism. The mesophilic phase begins at the outside temperature and acidic pH where compounds that are easiest to degrade starts to breakdown. The release of heat from the metabolism of microbes, along with release of ammonia from the breakdown of protein will start to raise temperature and pH. Temperature in this phase ranges from 5.0-5.5 to 8-9.
2. Thermophilic phase – at 45°C, activity of mesophilic bacteria ceases while the heat loving thermophilic microbes starts to activate. Biodegradation of BDP increases drastically during this phase due to the high temperature, however temperature needs to be controlled so it doesn't exceed 70°C which would deactivate and even kill thermophilic bacteria. pH in this phase will decrease towards neutral.
3. Cooling/maturation phase – compost starts to cool down when easily accessible carbon sources starts to decline which leads to the decline in temperature. Mesophilic microbes different from the first phase begin to appear with an increase in the amount of actinomycetes. The occurrence of these new microbes helps breakdown compounds that are more difficult to degrade.

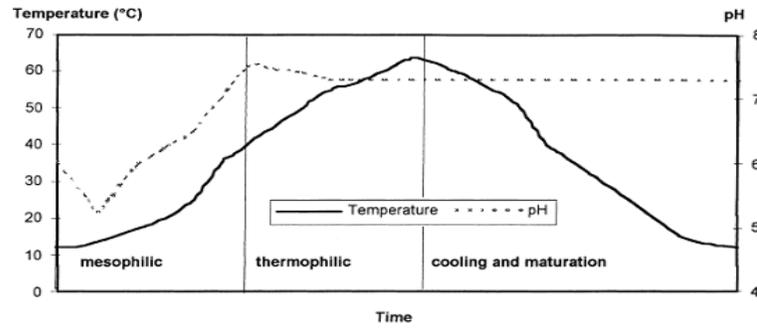


Figure 2. Typical pH and Temperature Profile During Composting

These three stages are present in composting units, however larger scale composters generally emphasizes more on the thermophilic phase for faster degradation.

1.3 Degradation of Biodegradable Polymers

There are several factors that affect the biodegradation of biodegradable polymers.

Some of the most significant factors include:

1. pH – At acidic pH, acidification of compost can occur, which would cause microbial activity to disappear, therefore pH has to be kept at around 6.5 – 8.0.
2. Moisture content – Higher moisture content allows for higher microbial activity which in turns helps degradation of the BDP product (S.B. Joo et al. 2005). Presence of moisture also means that water content is higher, which increases the rate of water hydrolysis of the polymer. However, moisture content above 70% would displace air in the compost which would affect oxygen transfer causing anaerobic environment. Typical moisture content for a composter is 40%-65%.
3. Oxygen content – Oxygen plays a role in the metabolism of the microorganisms, therefore high oxygen content is required in order to avoid anaerobic environment. However, too high of oxygen content would cause heat accumulation in the composter

increasing the temperature. Aeration in the composter can be adjusted so that cooling rate of air flowing in is equal to the heat evolution by microbes.

4. Temperature – Temperature is one of the crucial parameter in a composter, generally temperature must be kept at below 70°C to avoid killing microbes, but high enough to keep enzymatic and water hydrolysis rates as high as possible (S.B. Joo et al. 2005). The best operating temperature is approximately 55°C – 65°C. Some polymers also reach their glass transition temperature (T_g) in this temperature range, which would cause them to be more fluid, which would increase hydrolysis rate (G. Kale et al. 2007).
5. Polymer material – Some polymers are easier to degrade than others. Polymers containing ester or amide groups allow for enzymes to bind and mineralize large chains of polymers; on the other hand large side chains such as styrene blocks enzymes from binding. Additives such as metals and co-polymers assist in the biodegradability of certain polymers.
6. Nutrient content – Along with carbon, oxygen, and nitrogen sources, microorganisms also require other nutrients to grow, these include metal ions, phosphorous, potassium, etc. Generally these elements are present in the composting environment as salts, however these nutrients may be depleted at high microorganism content which would inhibit growth.

Other factors were also found to have an impact on the degradation. One of such is the biofouling of polymer surfaces during biodegradation (C.A. Woolnough et al. 2008). The source of compost materials such as inoculum substrates would also have an effect in the number of

microorganisms present, with mature compost having the largest value of microorganism (S. Wang et al. 2005)(K.M. Lee et al. 2005).

2.0 Thesis Objectives and Relevance

The objective of this thesis is to study the compostability of different biodegradable polymer products under varied composting conditions using laboratory-scale tests and pilot scale tests that will be conducted in the UBC in-vessel composter. This project was also done in collaboration with the UBC SEEDS project in order to determine the viability of biodegradable plastic products currently employed by the UBC Alma Mater Society for uses around the UBC campus. The goal of the UBC SEEDS project is to create a greener and more sustainable campus through the collaboration of students, faculty and staff including the UBC Waste Management. The problem currently being faced by UBC Waste Management is that the biodegradable cutleries were not found to degrade in the UBC in-vessel composter; therefore alternatives need to be explored in order to find a working solution that allows for sustainability.

3.0 Experimental Set-up

This Project consisted of two groups of tests, laboratory-scale tests that were conducted in Dr. Anthony Lau's lab, and pilot-scale tests that were conducted at the UBC in-vessel composter. In both sets of tests, different BDP products were tested to examine their compostability under specified composting conditions.

3.1 Tested Polymer Products

Five products were tested in this project whereby each BDP product has its own significance around the UBC campus.

1. Biodegradable Solutions International (BSI) cutleries – The BSI cutleries are supposed to be made of PLA which was fermented using corn starch as substrate. These cutleries are currently being used by the UBC Food Services as disposable cutleries, and ended up daily in the UBC in-vessel composter. Since they were found not to degrade within the two weeks of active phase composting; testing on the degradability of this polymer is required. It shall be noted that recently, BSI claimed polypropylene was added into the polymer mixture to give it the desired physical characteristics. This additional component might cause the BDP to degrade slowly.
2. Biodegradable Food Services (BFS) cutleries – Similarly, the BFS cutleries are made from PLA, but fermentation of the lactic acid monomer was done using potato wash as a substrate. In fact, life cycle analysis of BSI versus BFS cutleries was done by Sin Yin Lee (2009); results indicated that the production of BFS uses five times less energy than BSI based on its manufacturing methods, agricultural effects, and transport of the product. Based on this information alone, BFS appears to be the more sustainable alternative; however, its biodegradability is yet to be determined.
3. Papermate™ pen casings – These pen casings are PHA based polymers produced by Mirel™ Bioplastics. The resin was specified as biodegradable in compost, soil, and water, but would take up to one year to completely degrade. Testing of this polymer under

optimum composting conditions was conducted to observe any signs of degradation within the typical 2-week active phase of composting.

4. BiobagTM biodegradable plastic bags – This product is a starch-PCL blend polymer produced by Novamont. Addition of starch to PCL renders the product more economical and more easily degradable but lacks a wider range of application as the polymer softens at 40°C and melts at 60°C (Lim et al., 1999). These polymers are known to biodegrade readily in composting environment; hence they were included in the lab-scale composting tests for comparison purposes.
5. RalstonTM oxo-biodegradable plastic bags – The oxo-biodegradable polymers are produced using polyethylene backbone with additives that assist in degradation. The additives generally come in the form of pro-oxidant ligand complexes of transition metal ions. Exposure to oxygen will cause these additives to be oxidized and weakens the bonds between polyethylene chains, which is followed by hydrolysis and finally biodegradation. These products are currently used as trash lining bags around UBC campus, and they will normally be disposed via landfilling or incineration in Metro Vancouver but not composting facilities because the contents are unsorted garbage.

3.2 Laboratory-Scale Tests

The lab-scale tests were conducted in 6L Dewar reactors (Cole Palmer Instruments, Vernon Hills, IL). The Dewar reactor is a double walled stainless steel container with vacuum in between the two walls. The stainless steel walls and vacuum insulates the heat inside the reactor from escaping. The reactor was wrapped in aluminum foil, surrounded with fibre-glass

insulation material, and kept inside a 0.8m ×0.8m×1m Styrofoam box in order to retain the maximum amount of heat. These insulations were required in order to conduct the self-heating method.

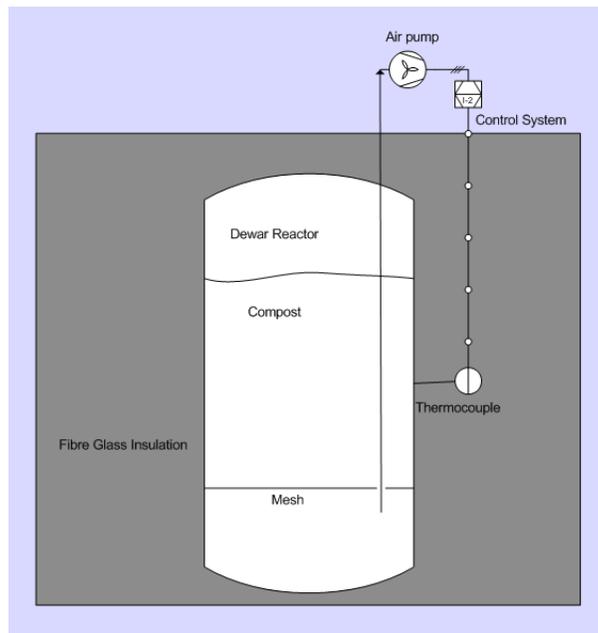


Figure 3. Dewar Reactor Set-up

As can be seen in figure 3, a mesh was placed inside the reactor, 500 mm from the bottom of the reactor as an air diffuser to disperse air fed into the reactor. Air was pumped into the reactors using aquarium-type air pumps, while the flow of air was determined using automatic controller with industry standard control strategy in order to keep the temperature at a set point of 65°C to maximize bacterial activity. Temperature sensor in the reactor was connected to a PC-based control system which connects to relay boxes and solenoid valves to control air supply.

Inoculum added into the reactor was in the form of mature compost and chicken manure, while pre-consumer food waste and yard waste were used as substrate. Wood chips and water were added into the mixture as a bulking agent to increase porosity and as means to

control moisture content respectively. Moisture content of each reactor was tested by oven drying a sample at 105°C for 24 hours and measuring the difference in mass, while porosity and carbon to nitrogen ratio were determined using pycnometer and CN analyzer respectively. Mature compost and chicken manure were then added to account for 10-20% of the total weight. Tables A-1 and A-2 presents the recipe of each reactor for the two runs that were conducted.

As seen in Tables A-1 and A-2, each reactor contained 2-3 different polymer products, with Biobag™ biodegradable bags being present in all runs as positive control for measure of degradation. Both biodegradable bag and oxo-biodegradable bag samples were placed into top, middle, and bottom layers of the compost in the reactors.

Each reactor was allowed to compost for 2 weeks (the active phase of composting) before removing the contents. The reactors were also monitored daily for any unusual temperature changes. At the end of 2 weeks, reactor contents were removed and polymer products were separated from the compost. Qualitative observations on degradation were made along with weight and tensile strength measurement if it was necessary.

3.3 Pilot-Scale Tests

The pilot-scale tests were done using the Wright Environmental in-vessel composter located on south campus of UBC. The composter allows for organic waste intake of up to five tonnes per day. Organic waste collected in green bins is dumped via forklift into a mixer along with wood chips, which are then loaded into the stainless steel composter via a conveyor. The mixture then drops onto a floor panel (tray) with small orifices which allows for aeration of the

compost mass. The floor panels then move through the three zones of the composter (with different prescribed setpoint temperatures) and with two sets of spinners for thorough agitation in between these zones. Exhaust air from the composter is ducted through the biofilter before it is released through a bed of soil for odour treatment. Temperature in the composter is continuously monitored and controlled using an automatic feedback controller. After 14 days residence time, compost exits the other end. In the past, the compost was screened (with a shaker screen) to separate large particles from smaller ones and to recover foreign objects. Figure 4 shows a schematic of the UBC in-vessel composter.

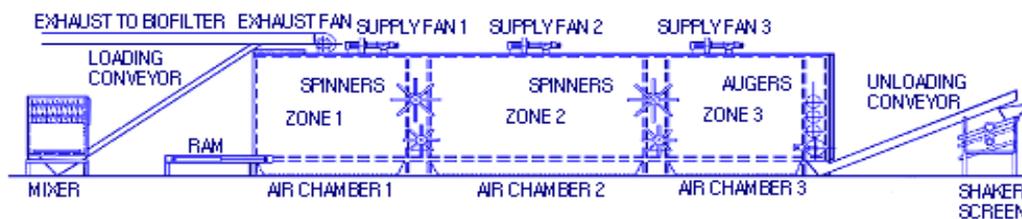


Figure 4. UBC In-Vessel Composter Schematic

In this project, BFS and BSI cutlery entered the composter at two different times. Each piece of cutlery was tagged using a permanent marker and the initial weight was recorded prior to dumping into the composter along with 1-2 tonnes of organic waste. The temperatures were monitored daily using the temperature sensors located in the four zones. At the end of the cycle, the samples were collected where mass and tensile strength were measured along with observations on any physical degradation.

4.0 Results and Discussion

4.1 Compost Temperature Profiles

The temperature profiles of the first run can be seen in figure 5 below.

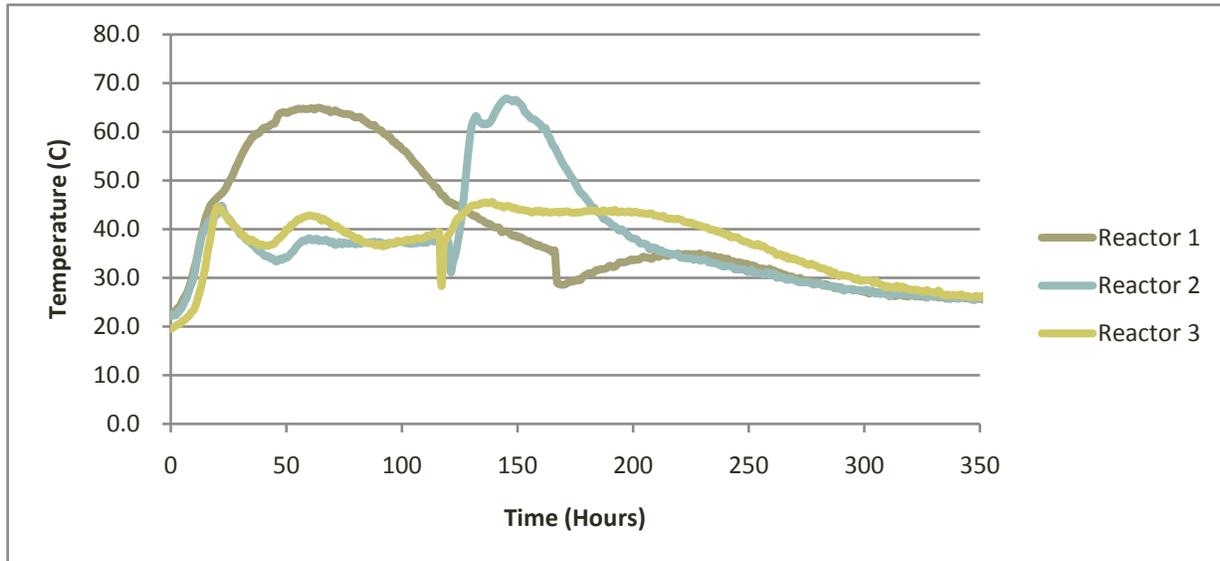


Figure 5. Run 1 Temperature Profile

Figure 5 shows that the temperature profiles are considerably different; this is due to various reasons. For reactor 1, the profile follows a typical composting profile, where it reached a maximum temperature of approximately 65°C. The dip observed at approximately 170 hours was due to the opening of the reactor and mixing the contents when the temperature was found to be declining prematurely. As a result, temperature reading dropped briefly, before climbing back and finally returning to room temperature at the end of the run.

Reactor 2 presented a slightly different case. As observed, there is a delay in the rise of temperature in reactor 2, which can be attributed to the denser packing inside the reactor. On

day 5, the reactor was opened and contents were mixed to allow for a looser packing, which resulted in the rise in temperature. Loosening of the packing allows for greater porosity; hence air can be better dispersed inside the reactor allowing for aerobic metabolism to occur. This would produce a larger amount of heat. Apart from the difference in packing density, reactor 2 may be considered as a replicate of reactor 1.

Reactor 3 temperature profile suggested that it did not go past the mesophilic regime into the thermophilic regime, which might be due to two factors, moisture content and inoculum. As can be seen in table A-1 the moisture content for reactor 3 was determined to be 80%; this is higher than expected and would affect the air-filled porosity and hence oxygen transfer efficiency. Moreover, the temperature profile of reactor 3 follows a similar trend as reactor 2 which also had problem with porosity during the first 5 days, indicating that porosity could play a role in allowing the compost to go into thermophilic phase. However, since the porosity problem of reactor 3 stemmed from moisture content instead of packing density, mixing of the reactor contents did not cause the temperature to rise. The second factor that could affect the results is the inoculum. The inoculum used in reactor 3 was in the form of mature compost only. The absence of chicken manure that was added into both reactors 1 and 2 might also imply the lack of thermophilic bacteria that would allow the compost to continue into thermophilic phase. This effect however cannot be made certain unless further studies into the flora of the two inocula are done.

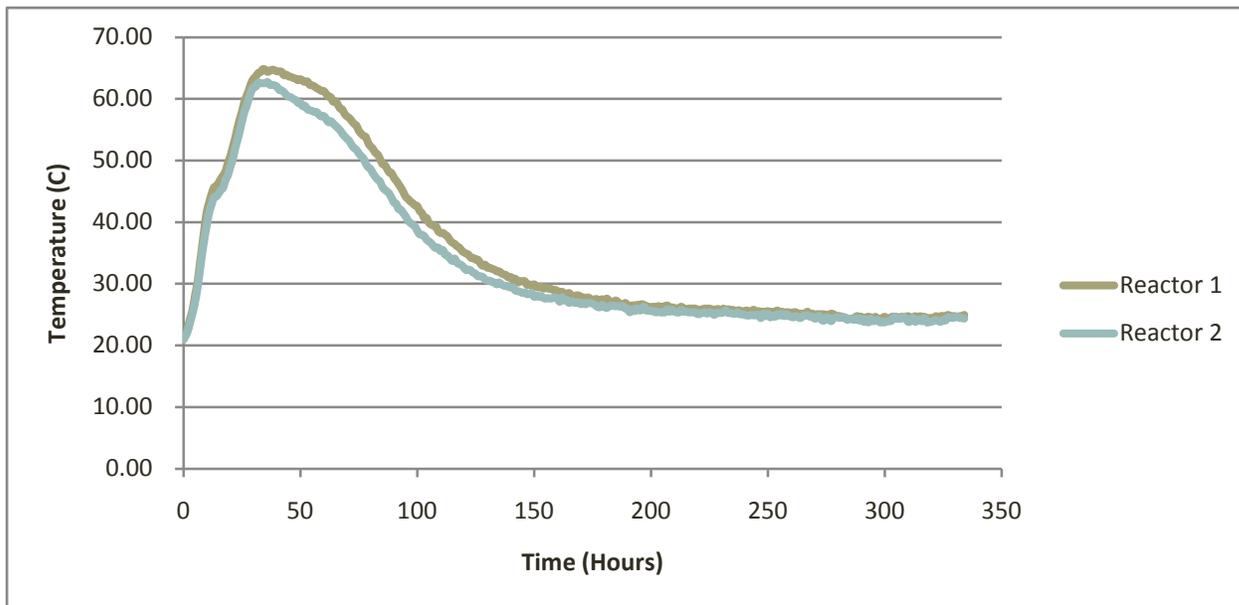


Figure 6. Run 2 Temperature Profile

As opposed to run 1 where variations are obvious in the temperature profiles, the two reactors conducted in run 2 were exact replicates of each other. Both reactors exhibit typical composting temperature profiles (Figure 6), as expected.

4.2 Qualitative Analysis of Polymer Degradation

The biodegradable polymer products were retrieved from each reactor after 2 weeks of composting and quantitatively analyzed for any degradation. Signs of degradation that are visible generally include discoloration, loss of mass, and significant change in physical characteristics such as flexibility and brittleness.

Biodegradable Plastic Bags

Three equal-sized pieces of Biobag™ biodegradable plastic bag samples were placed into each reactor at different depths in the reactor. The products after composting can be seen in figure 7 below.

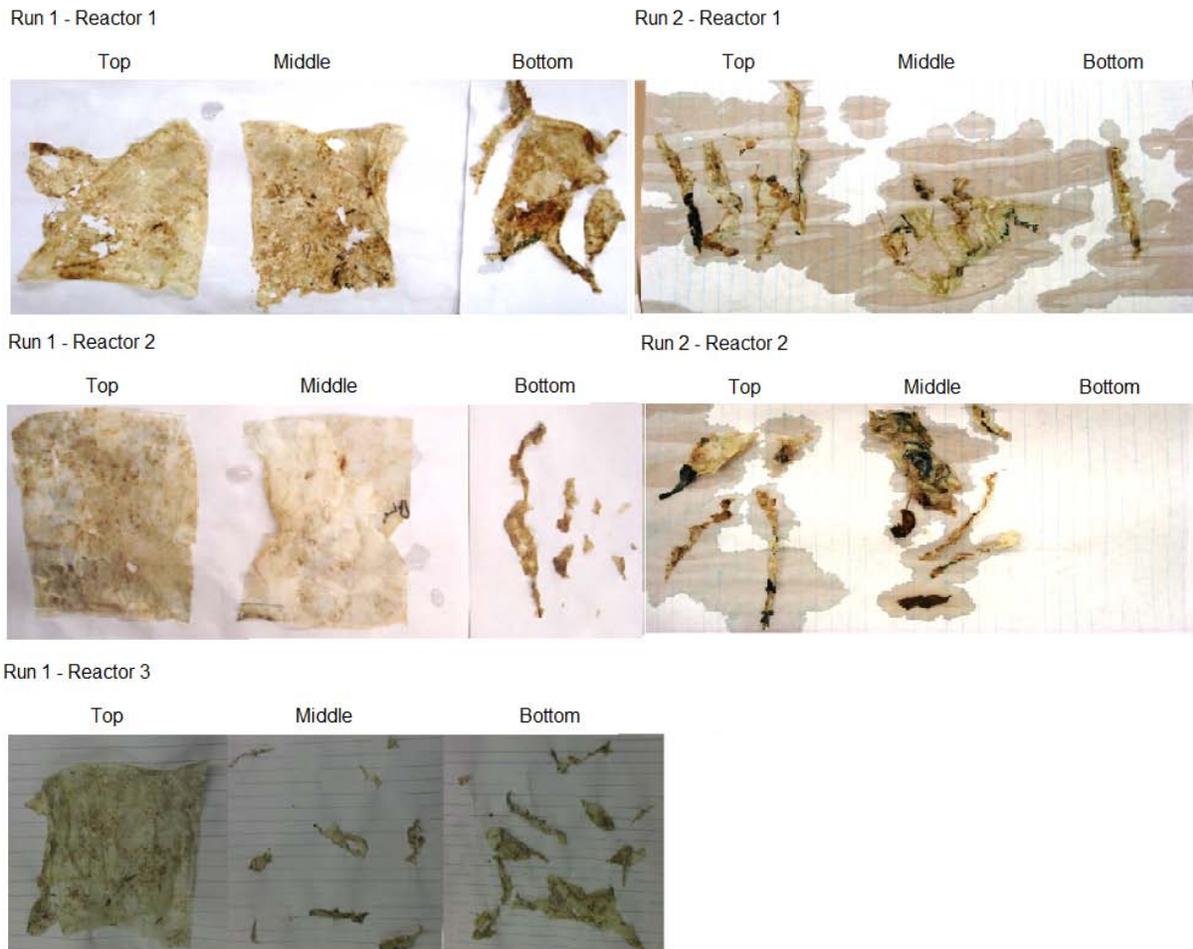


Figure 7. Biobag™ Biodegradable Plastic Bags Post-Composting

The plastic bag samples were observed to degrade up to 90% almost consistently. The general trend is that pieces located in the bottom layer of the reactor were found to have degraded much more than pieces placed in the top layer of the reactor. It is unclear why this is exactly so, but a few theories can be used. The first and most likely theory is that the compost material becomes more compact during composting and exerts greater pressure on the plastic samples, thus causing the plastic to stretch thin. This, in turn, would increase surface area and weaken some bonds, thereby allowing faster degradation. Another possible reason is that since

the exhaust is located at the top, heat is being removed faster in that region. Additionally, there is less insulation near the top region compared to the bottom, thus causing the temperature at the top to be lower than that at the bottom.

The biodegradable plastic bag samples located inside reactor 3 were found to have degraded more than reactors 1 and 2 during the first run, indicating that thermophilic temperatures might not be necessary for the degradation of this product. It also indicates that the effect of moisture content is significant. In a previous test, these plastic bag samples were placed in hot water for three weeks; degradation was not observed, but the bags exhibited discoloration. At 80% moisture content, therefore, hydrolysis by water could be more prevalent than bacterial activity due to oxygen limitations; however degradation of the plastic is still significant. This presents a possibility in optimization between the two parameters which will be further covered in the recommendation and future works section.

Oxo-biodegradable Plastic Bags and Polyhydroxyalkanoate Pen Casings

As observed in figure 8, the oxo-biodegradable bags showed no signs of degradation during the span of two weeks inside the reactor, not even discoloration. Although these oxo-biodegradable bags are supposed to degrade over longer periods of time, it seems like its method of degradation is not suited for short term composting. And it will take much longer to degrade in landfills. For proper degradation, metal ion additives found inside the polymer chains will become oxygenated which will weaken the bonds and cause it to be readily mineralized by microorganisms.

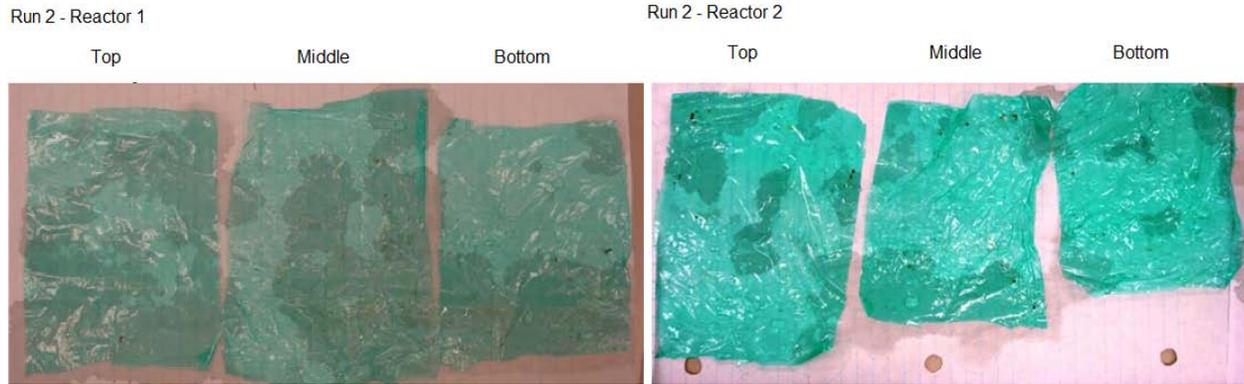


Figure 8. Oxobiodegradable Plastic Bags Post-Composting

Similarly, the Mirel™ pen casings were not found to show any signs of degradation (Figure 9). This is as expected, since the manufacturer indicated it would require up to one year for complete degradation in soil. It shall be noted that other PHA polymers have been found to degrade completely in a 10-week composting environment at 60°C, 55% moisture, and 18:1 C:N ratio (Gallagher, 2001).



Figure 9. Mirel™ Pen Casings Post-Composting

BFS and BSI Cutleries



Figure 10. BSI Cutleries Post-Composting

Figure 10 shows the resulting BSI knife after composting for both reactors 1 and 2. As observed, there was no physical degradation for the polymer for both whole and cut BSI knives. These results were as expected since the degradation in the lab-scale composter is expected to be less than the in-vessel composter. The dark spots found on the surface of the polymers were found to be stains from composting instead of discoloration.



Figure 11. BFS Cutleries Post-Composting

The BFS Cutleries on the other hand, showed some sign of potential disintegration. As observed in figure 11, no physical degradation was seen with these polymers; however, a comparison of the BFS plastic sample before and after composting in figure 12 clearly shows some discoloration, which indicates that perhaps more time is required before some physical degradation can be observed. A very small weight change (-2%) was recorded; however, it is far from conclusive due to lack of samples tested.



Figure 12. Comparison of BFS Spoons

4.3 Pilot-Scale Composting Results

A few problems were encountered while conducting the pilot-scale composting tests. The marked BSI cutleries were inserted into the in-vessel composter on February 12th, to be collected around March 1st. However, on February 15th the in-vessel composter was down due to mechanical issues and did not continue to run until February 25th. This problem was remedied by collecting various BSI cutleries available coming out of the composter and determining the average measurements before and after composting. The other difficulty that was met was with the BFS cutleries. The BFS cutleries were placed into the composter on March 12th and were expected to be collected on March 30th. On March 30th however, the BFS cutleries were not found in the exiting compost pile. While they are expected to degrade better than the BSI cutleries, pronounced physical degradation is very unlikely after one pass through the composter. The BFS samples are currently located in the compost curing piles which will be screened at a later date and collected for observations and measurements of degradation.

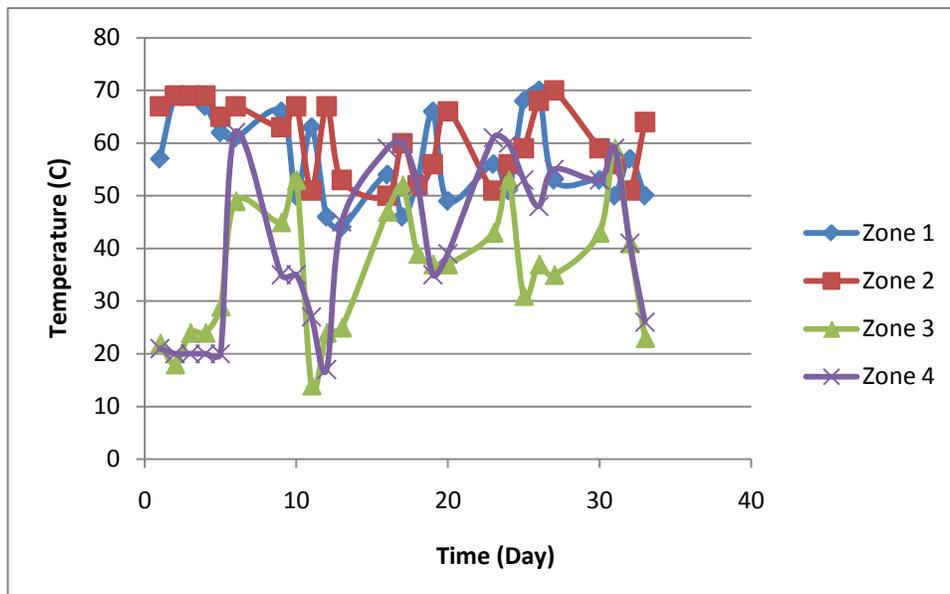


Figure 13. UBC In-Vessel Composter Temperature Progression

Figure 13 shows the temperature progression during the month of March for the four zones of the composter. Large variations in the temperature can be observed here especially for zones 3 and 4, while zones 1 and 2 stayed in the range of 50-70°C. These variations in temperatures could perhaps be attributed to a few reasons. The first reason, since the only heat source present in the composter is from the bacteria, environmental factors such as ambient temperatures, wind velocity, wind chill, and precipitation could easily affect the temperature profile inside the composter. Secondly, each tray going into the composter does not have the same composition. Factors such as moisture content, fibre content, C:N ratio that would affect composting could vary between each tray entering the composter; hence variations in the temperature profiles from the ideal situation were realized.

The general trend that can be observed for each tray follows that of a typical composting temperature profile. A few sample temperature profiles taken over the month of March can be seen in figure 14 below.

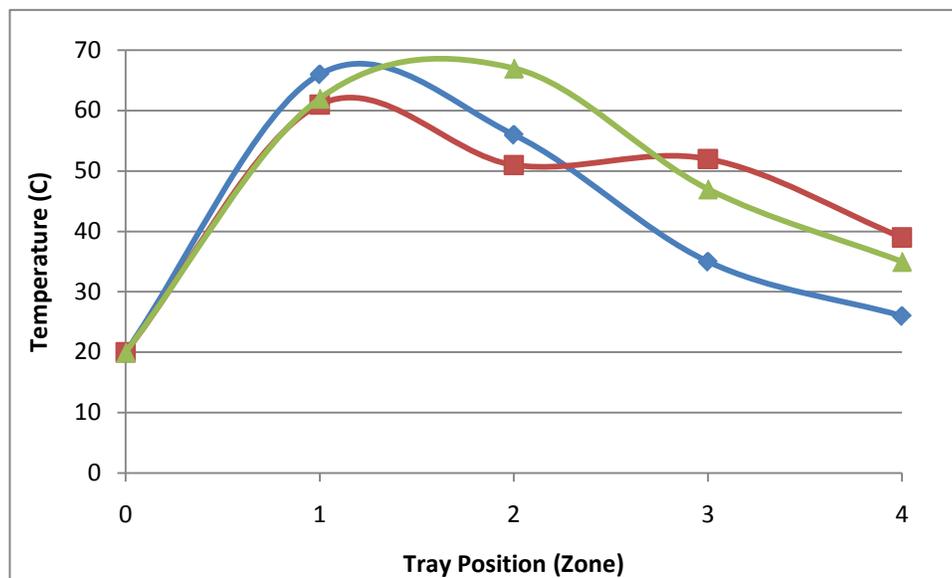


Figure 14. Temperature Profile of Sample Trays inside In-Vessel Composter

Figure 14 shows that temperatures follow a typical composting temperature profile. Zones 1 and 2 represent the thermophilic zone similar to the lab-scale results, which then decreases as it enters zone 3 and 4. The overall temperatures for the pilot-scale tests were higher than those for lab-scale tests since it is constantly mixed throughout along with greater composting mass.



Figure 15. BSI Cutleries after Pilot-Scale Composting

The BSI samples collected from the composter as seen in figure 15 were found to be broken and distorted, but there were no signs of degradation. These results were as expected, but any degradation cannot be seen unless weight and tensile strength measurements are conducted. Other studies have found that PLA polymers undergo water hydrolysis during the first 2 weeks of composting at 60°C in a large scale operation. At temperatures under 60°C however, PLA were not found to readily biodegrade since 60°C is its glass transition temperature (Nolan-ITU Ltd. 2002).

4.4 Tensile Strength Analysis

Figures A-5 to A-7 represents the tensile strength measurements conducted in the Forest Science Department. The tensile strength of 5 composted, 5 uncomposted, and 1 lab-scale composted samples of BSI knives were analyzed for differences in tensile strength.

As observed, there are significant differences between the uncomposted and composted samples. The average maximum loading for the uncomposted samples were found to be 366 N with average maximum extension at breakpoint of 6.3 mm. On the other hand, the composted samples had an average maximum loading of 408 N and an average maximum extension at breakpoint of 10.5 mm. The lab-scale composted sample had a maximum loading of 388 N and a maximum extension of 16.5 mm. Overall, the composted samples were found to be stronger and more ductile than the uncomposted samples. Although it is unclear why the material has become stronger and more ductile post-composting, it is thought to be the effect of water hydrolysis. If bonds were starting to break in the internal structure of the polymer due to hydrolysis, then it is likely that the polymer will become less brittle and more ductile, indicating that degradation has started to occur. If this hypothesis is true, then a plot of maximum load and maximum elongation over time would present a parabola-like curve where a maximum tensile strength will occur before weakening.

5.0 Recommendations for Future Work

Since the project was only conducted over the duration of 3 months, many changes and additions towards the project could be done in order to do a more in-depth study on the biodegradation of these polymers.

5.1 Recommendations for Laboratory-Scale Tests

The problem that was constantly met during the laboratory scale tests was that the thermophilic phase only lasted approximately 2 days before returning to mesophilic phase, and soon after, ambient temperature. This problem could be solved in two ways. The first method is to constantly replenish the limiting nutrients, which is most likely to be nitrogen. Nitrogen source could be fed into the reactor in readily usable form such as nitrate or ammonia. The second method is to use a heating jacket in order to control the temperature profile of the reactor to be as desired though it will be non-self-heating. This heating jacket method also allows for expansion into testing using ASTM Standards. Another addition that could be implemented into the project is the testing of PLA resins to be obtained from Dr. Hatzikiriakos' lab in order to compare the degradation between the varieties of PLA polymers which could also be done under the ASTM standard.

The ASTM protocol is different from the self-heating method in a few ways. The first is the usage of heating jacket to maintain optimal temperature of 58°C at all times. Fully mature compost with a diverse microorganism population must also be used along with constant feeding of nutrients with the purpose of measuring the degradation of the polymer itself instead of the compost. Lastly, the duration of the testing will also be prolonged up to 180 days in order to observe degradation of the polymer. By using the ASTM method, constant measurement of the polymer mass can be done to keep track of degradation.

5.2 Recommendations for Pilot-Scale Tests

The problem that occurred in the collection of BFS samples could be fixed by conducting a screening directly after the compost exits the composter. A metal wire could also be used in

place of permanent ink marker for tagging since the markings were found to have washed off due to combinations of abrasion, moisture, and heat in the composter. Additionally, a larger sample size of BFS could be placed into the composter so that recovery of the samples can be easier.

Since no degradation was observed for BSI samples and no significant physical degradation is expected from the BFS samples, multiple runs through the composter would allow for an approximation of how long it will take until significant degradation occur. However, to conduct this test, the aforesaid recommendations to better track cutlery samples must be implemented. After determining the length of time it will take for significant degradation to occur, a simple mass balance could be applied to the composter to determine if the same “recycle” method is viable to permanently fix the problem with un-degraded cutleries.

Aeration of the outdoor curing piles that follow the two-week active phase composting in the in-vessel composter will also allow for mesophilic temperatures to be maintained for a longer period of time, so that the biodegradable polymers can eventually degrade. However, this method necessitates additional equipment, and it is more labour intensive, which might not be economically feasible.

A combination of the continuous recycling and curing-pile aeration methods would most likely provide the best result in the degradation of the BDP cutleries. For example, a certain cutlery would enter the composter for the first time and exit to be screened. The collected un-degraded cutleries can then be continuously recycled back into the composter until significant degradation would cause the cutleries to pass the screener where it will be collected in an aerated curing pile to complete its degradation.

6.0 Conclusion

The objective of this project to study the compostability of different biodegradable polymer products was partially met through laboratory-scale tests and pilot-scale tests that were conducted at the UBC in-vessel composting. From information gathered through these tests, it was concluded that apart from Biobag™ biodegradable plastic bags, the rest of the polymers tested showed very little or almost no signs of degradation, indicating that 2 weeks of composting is not enough to observe degradation on these products. However, it was shown from qualitative analysis of the laboratory-scale composting results, that the BFS cutleries showed some signs of discoloration, which indicate that BFS polymers would most likely degrade faster than BSI. Additionally, a life-cycle analysis comparing BFS and BSI polymers conducted by Sin Yin Lee, a UBC Chemical and Biological Engineering student in 2009 showed favour for BFS. Although more conclusive studies are needed to determine the exact timeframe required for complete biodegradation, it seems like BFS cutleries is the better alternative compared to the currently employed BSI cutleries.

In order to fully utilize the advantages biodegradable polymer products have over conventional polymers, knowledge of how these polymers degrade in available facilities is required. Further in-depth studies into the differences between the two PLA cutleries and the degradation of other various biodegradable polymers can be done using the recommendations outlined in this report. Using this acquired knowledge, the goal of creating a green and sustainable campus will be one step closer.

Nomenclatures

ASTM	American Society for Testing and Materials
BDP	biodegradable polymer
BFS	Biodegradable Food Services (supplier)
BSI	Biodegradable Solutions International (supplier)
PCL	polycaprolactone
PHA	polyhydroxyalkanoates
PLA	polylactic acid

References

- Croteau, G. (1998). Assessing the Degradability of Polymeric Materials. *BioCycle* , 39(3):71-75.
- Davis, G., H., B., D., H., & E., B. (n.d.). An Evaluation of Degradable Polyethylene Sacks in Open Windrows Composting. *Compost Sci. Utiliz* , 13(1):50-59.
- Edited by: Bastioli, C. (2005). *Handbook of Biodegradable Polymers*. Smithers Rapra Technology.
- European Bioplastics. (2009). *Position Paper: "Oxo-Biodegradable" Plastics*. Berlin.
- Greene, J. P. (2006). Biodegradation of Compostable Plastics in Cow-Manure Compost Environment. *Society of Plastics Engineers - Global Plastics Environmental Conference GPEC* (pp. 25-30). Atlanta: Society of Plastics Engineers.
- Han, X., & Pan, J. (2009). A Model for Simultaneous Crystallisation and Biodegradation of Biodegradable Polymers. *Biomaterials* 30 , 423-430.
- Jang, J. C., Shin, P. K., Yoon, J. S., Lee, I. M., Lee, H. S., & Kim, M. N. (2001). Glucose Effect on the Biodegradation of Plastics by Compost From Food Garbage. *Polymer Degradation and Stability* 76 , 155-159.
- Joo, S. B., Kim, M. N., Im, S. S., & Yoon, J. S. (2005). Biodegradation of Plastics in Compost Prepared at Different Composting Conditions. *Macromol. Symp.* , 355-365.
- Kale, G., Auras, R., Singh, S. P., & Narayan, R. (2007). Biodegradability of Polylactide Bottles in Real and Simulated Composting Conditions. *Polymer Testing* 26 , 1049-1061.
- Korner, I., Redemann, K., & Stegmann, R. (2005). Behavior of Biodegradable Plastics in Composting Facilities. *Waste Manage* , 25:409-415.
- Koutny, M., Lemaire, J., & Delort, A. (2006). Biodegradation of Polyethylene Films with Prooxidant Additives. *Chemosphere* , 64:1637-1640.
- Lee, K. M., Gimore, D. F., & Huss, M. J. (2005). Fungal Degradation of the Bioplastic PHB (Poly-3-hydroxybutyric acid). *Journal of Polymers and the Environment* vol 13 , 213-219.
- Li, H. H., & Lau, A. K. (2008, August). Decomposition of Biodegradable Polymers in the Composting Process. *Master of Engineering Report* .
- Lim, S. W., Jung, I. K., Lee, K. H., & Jin, B. S. (1999). Structure and Properties of Biodegradable Gluten/Aliphatic Polyester Blends. *Eur. Polym. J.* , 35, 1875-1881.
- Nolan-ITU Pty Ltd. (2002, October). *Biodegradable Plastics - Developments and Environmental Impacts*. Retrieved March 2010, from Australian Government, Department of the Environment, Water, Heritage and the Arts:
<http://www.environment.gov.au/settlements/publications/waste/degradables/biodegradable/index.html>
- Reddy, M. M., M, D., Gupta, R. K., Bhattacharya, S. N., & Parthasarathy, R. (2008, June 19). *Biodegradation of Oxo-Biodegradable Polyethylene*. Retrieved from Wiley Interscience: www.interscience.wiley.com

- Rychter, P., Biczak, R., Herman, B., Smylla, A., Kurcok, P., Adamus, G., et al. (2006). Environmental Degradation of Polyester Blends Containing Atatic Poly(3-hydroxybutyrate). Biodegradation in Soil and Ecotoxicological Impact. *Biomacromolecules* , 3125-3131.
- Shaw, K. (1998). Evaluating Degradable Polymers in Controlled Laboratory Environments. *BioCycle* , July:75-82.
- Woolnough, C. A., Charlton, T., Yee, L. H., Sarris, M., & Foster, L. J. (2008). Surface Changes in Polyhydroxylkanoate Films During Biodegradation and Biofouling. *Polymer International* , 1042-1051.
- Yang, H. S., Yoon, J. S., & Kim, M. N. (2004). Effects of Storage of a Mature Compost on its potential for Biodegradation of Plastics. *Polymer Degradation and Stability* 84 , 411-417.
- Yue, C. L., Gross, R. A., & McCarthy, S. P. (1995). Composting Studies of Poly(hydroxybutyrate-co-hydroxyvalerate). *Annual Technical Conference - ANTEC* (pp. 2033-2036). Boston: Society of Plastic Engineers.

Appendix A – Additional Figures and Tables

Reactor	1	2	3
Substrate	Food waste and grass clippings; sawdust; wood chips as bulking agent		
Inocula	Mature compost and chicken manure	Mature compost and chicken manure	Mature Compost
Total mass	1.05 kg	0.85 kg	1.05 kg
Moisture content	71.2%	71.7%	80.1%
C:N ratio	28.2	26.5	29.4
Bulk density	375 kg/m ³	325 kg/m ³	443 kg/m ³
BDP products present	BSI cutlery (intact) Biobags	BSI cutlery (shredded) Biobags	pen casing Biobags

Table A 1. Run 1 Feedstock Composition and Characteristics

Reactor	1	2	3
Substrate	Food waste and grass clippings; sawdust; wood chips as bulking agent		
Inocula	Mature compost and chicken manure	Mature compost and chicken manure	Mature Compost
Total mass	1.05 kg	0.85 kg	1.05 kg
Moisture content	71.2%	71.7%	80.1%
C:N ratio	28.2	26.5	29.4
Bulk density	375 kg/m ³	325 kg/m ³	443 kg/m ³
BDP products present	BSI cutlery (intact) Biobags	BSI cutlery (shredded) Biobags	pen casing Biobags

Table A 2. Run 2 Feedstock Composition and Characteristics



Figure A 1. Dewar Reactor Setup



Figure A 2. Temperature Data-Logging System



Figure A 3. UBC In-Vessel Composter



Figure A 4. Reactor Contents after 14 Days Composting

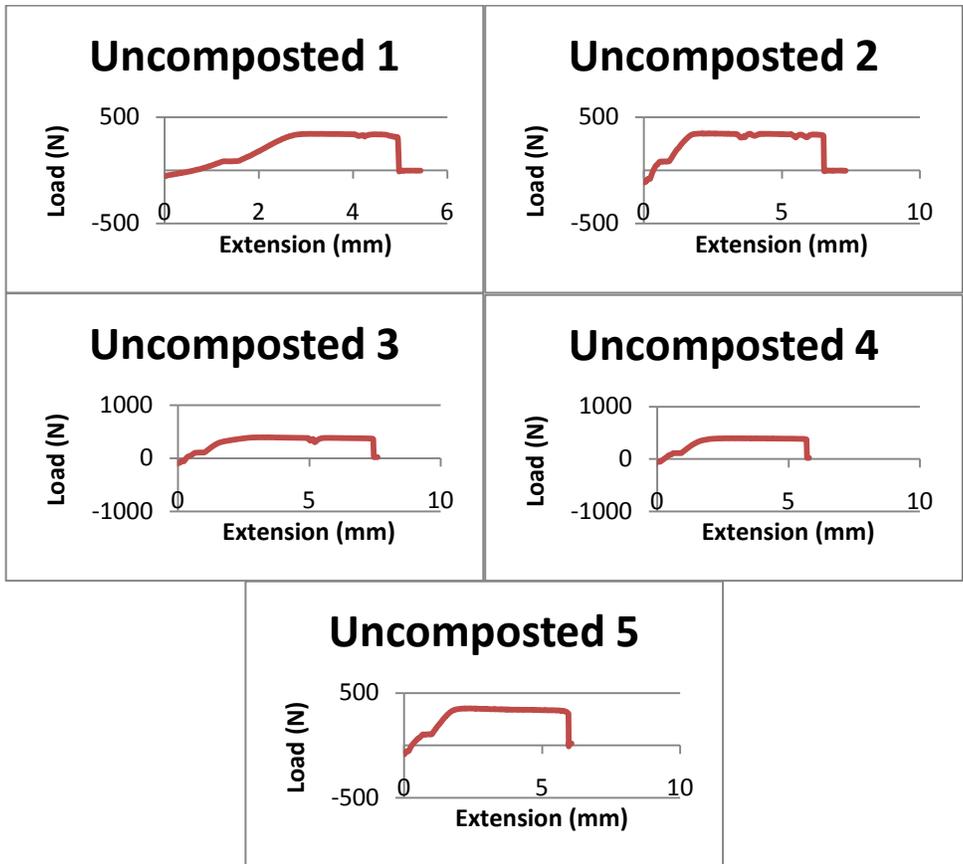


Figure A 5. Tensile Strength Analyses for 5 Uncomposted BSI Knives

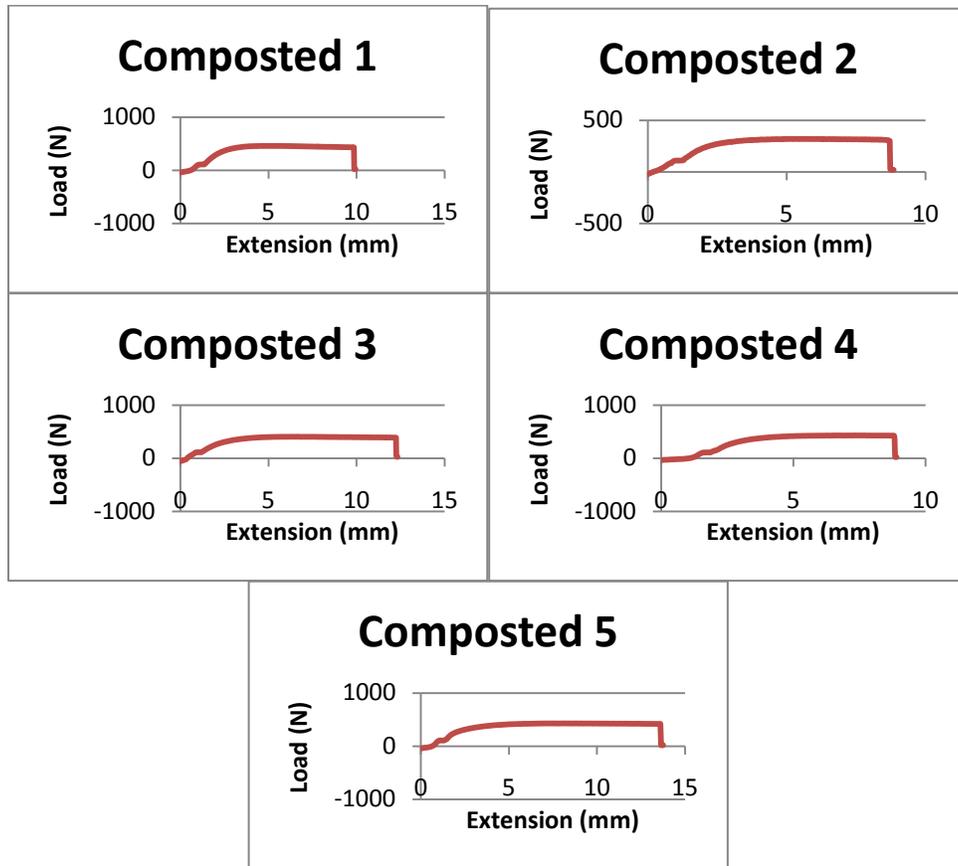


Figure A 6. Tensile Strength Analyses for 5 Composted BSI Knives

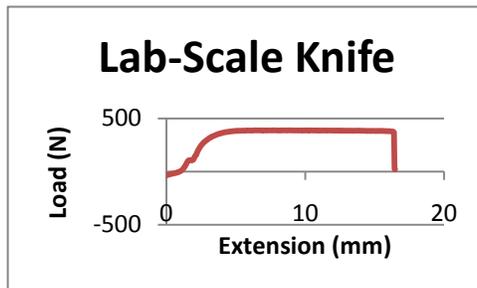


Figure A 7. Tensile Strength Analysis for Composted Lab-Scale BSI Knife