E344
Workshops for Societal Impact – Microplastic Reduction

Bacterial Biodegradation for Bottles

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Abstract

Plastic bottles make up most of the waste pictured in photographs of landfills. What is not seen in these photographs and what I did not know about before this course is the microplastics that are left after the bottle is left for years. PET bottles are unable to fully decompose in landfills and leave behind microplastics that pollute the environment. This report explains a method of re-engineering PET bottles to reduce the number of microplastics that sprout from their manufacturing. This method breaks down microparticles left behind by PET bottles so that fewer remain after decomposition. Challenges associated with this idea include the cost, the time consumed, and the payoff may not appear to be worth it to beverage companies.

Introduction

When people think of pollution, they think of landfills piled high with mountains of garbage. A more concerning aspect of these plastics is the microplastics that they break down into. This is a concept which was unfamiliar to me before taking this class. Plastics break down into microplastics because of their bonding types. A plastic bottle is not exactly the strongest object, however the secondary bonding that makes up the polymer PET which makes up that plastic bottle is incredibly strong.

The problem with microplastics and pollution is that microplastics end up in ecosystems and directly impact life there. An example of this is found in ocean habitats. Plastics end up washing into the ocean and there they will be consumed by aquatic animals. These animals could then be consumed by humans since roughly half of all seafood is caught in the wild. The figure pictured below shows an example using shellfish, a popular seafood dish.

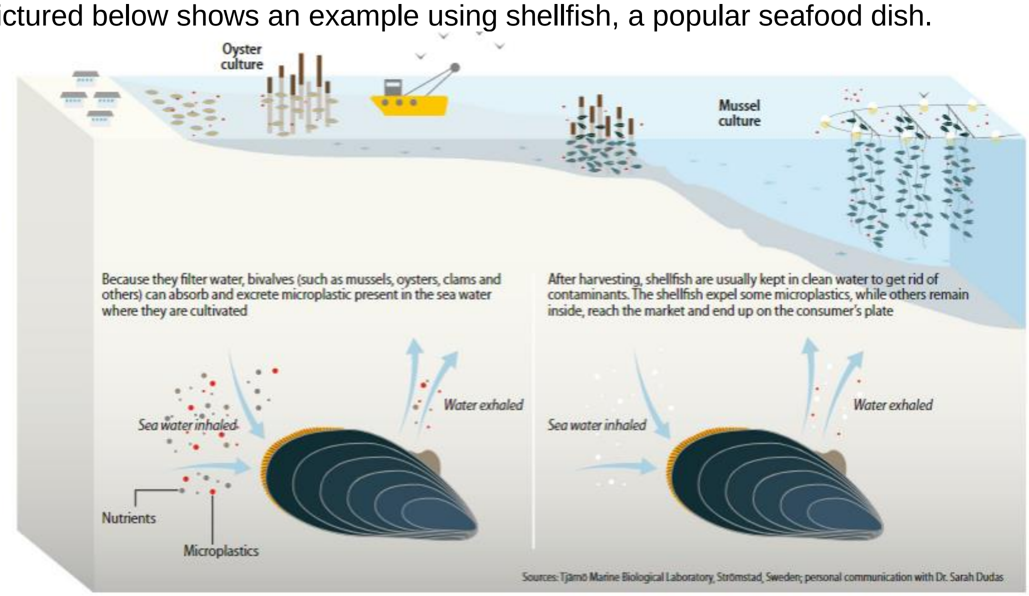

Figure 1. Human Consumption of Microplastics

One can easily see that humans are not far removed from the consumption of microplastics. Already microplastics impact the lives of animals who eat them, and humans eating the microplastics indirectly through those animals should help to raise awareness about the issue. The sad fact is that this problem will only worsen with time and the time to act is now, not later.

The current solution for removal of PET waste includes landfills, incineration, or recycling. The problem with landfills is that it occupies too much land, it pollutes water around the environment, emission of harmful materials, and it wastes too many resources. Incineration also pollutes the air horribly, so it is not a good option either. Finally, recycling is limited because of high costs and over time the cost to recycle PET has risen. Many companies have stopped recycling due to it costing too much and having little gain in terms of wealth. Therefore, the solution must come from re-engineering the plastic that is used to make PET bottles.

Specific Product-Related Problem

The topic for this report came to me from the protein shakes that I drink daily. Polyethylene terephthalate is the material that is used to make the bottles that my Fairlife Core Power protein shakes, and I drink at least one of these shakes per day. When I was 16, I sustained massive orthopedic injuries to my upper and lower extremities as well as my pelvis. I spent months hospitalized and had a very long, rigorous recovery process. An integral part of this recovery was gaining weight that I had lost while being bedridden in the hospital. When I left the hospital, I was under 100 pounds and 6 feet tall, so I was very underweight. To gain weight back I had to eat a lot of calories and protein and the easiest way to add more to my calory count daily was to throw in a protein shake or two. Since the shakes are so dense in calories and protein, they are easy to add to a diet and not as hard to eat as an extra meal. To this day, they are still a part of my diet as I try to continue to gain weight and get to where I want to be physically. I recycle them, but then even if they are reused or made into something else, that does not stop them from eventually ending up in a landfill and turning into microplastics.

Polyethylene terephthalate drink bottles were one of the first kinds of post-consumer plastics to be recycled in significant amounts. Over time, however, the rate of recycling for these products has been declining. I once saw this first-hand at my high school where I saw the janitors take the garbage can and the recycling can in the classroom and pour both into the same garbage bag. This must be the case in many places where one may think that they are recycling and helping only to see that their bottles end up in a landfill. The decline in recycling is mainly attributed to the growth in single-serving bottles since consumers like to buy and finish these drinks while away from home, so they are less likely to be properly recycled. Also, over time the value of recycled PET has been dropping which makes recycling the products less profitable and has made some recyclers cease operations. This product is useful in its primary use as a container for drinks, and it is an important product because it is one of the most used materials to fill that purpose.

PET is mainly used as packaging primarily for drinks. Specifically storing drinks like water or soft drinks in bottles. It is especially popular for bottling sodas since it has strong gas battier properties. PET has a value almost as good as that of aluminum, which is why sodas are almost always seen either in cans or in PET bottles. It is also sometimes used as a substitute for cotton in polyester fibers, but this area has the same problem where the PET used eventually breaks down into microplastics and is not the focus of this report.

Materials properties are copied here in figs 2-6 and are provided by Granta EduPack, I call specific attention to the CO_2 footprint from its manufacturing. This is another big problem that stems from PET bottles but that will not be tackled in this report. This report focuses on the microplastics left behind by these bottles.

General properties

Density	0.0466	-	0.0502	lb/in^3
Price	* 0.481	-	0.599	USD/lb
Date first used	1941			

Figure 2. General Properties

Mechanical properties

Young's modulus	* 0.405	-	0.437	10^6 psi
Shear modulus	* 0.144	-	0.216	10^6 psi
Bulk modulus	* 0.716	-	0.753	10^6 psi
Poisson's ratio	* 0.38	-	0.4	
Yield strength (elastic limit)	* 7.25	-	7.98	ksi
Tensile strength	7.98	-	8.7	ksi
Compressive strength	* 7.25	-	8.7	ksi
Elongation	280	-	320	% strain
Hardness - Vickers	* 2	-	5	HV
Fatigue strength at 10^7 cycles	* 2.8	-	4.21	ksi
Fracture toughness	* 4.32	-	4.78	ksi.in^0.5
Mechanical loss coefficient (tan delta)	* 0.00966	-	0.0145	

Figure 3. Mechanical Properties

Thermal properties

Melting point	458	-	530	°F
Glass temperature	140	-	183	°F
Maximum service temperature	* 131	-	149	°F
Minimum service temperature	* -72.7	-	-36.7	°F
Thermal conductor or insulator?	Good insulator			
Thermal conductivity	0.0797	-	0.139	BTU/hr.ft.°F
Specific heat capacity	0.275	-	0.299	BTU/lb.°F
Thermal expansion coefficient	63.9	-	66.1	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good insulator			
Electrical resistivity	1.3e20	-	1.18e21	µohm.in
Dielectric constant (relative permittivity)	3.5	-	3.7	
Dissipation factor (dielectric loss tangent)	* 0.003	-	0.007	
Dielectric strength (dielectric breakdown)	914	-	1.12e3	V/mil

Figure 4. Thermal and Electrical Properties

Geo-economic data for principal component

Annual world production, principal component	ⓘ	1.85e7			ton/yr
Reserves, principal component	ⓘ	1.21e8	-	1.33e8	l. ton

Figure 5. Geo-Economic Data

Material processing: CO2 footprint

Polymer extrusion CO2	ⓘ	* 0.437	-	0.483	lb/lb
Polymer molding CO2	ⓘ	* 1.4	-	1.55	lb/lb
Coarse machining CO2 (per unit wt removed)	ⓘ	* 0.0648	-	0.0716	lb/lb
Fine machining CO2 (per unit wt removed)	ⓘ	* 0.327	-	0.361	lb/lb
Grinding CO2 (per unit wt removed)	ⓘ	* 0.618	-	0.684	lb/lb

Figure 6. CO2 Footprint

PET is produced from petroleum hydrocarbons, through a reaction which occurs between ethylene glycol and terephthalic acid (shown in Fig. 7). The PET is then polymerized to create these long molecular chains which allow PET bottles to be produced later. The process of polymerization is a complicated one and is what differentiates batches of manufactured PET. Normally, there are two impurities during polymerization: diethylene glycol and acetaldehyde. Diethylene glycol is generally not made in high enough amounts to affect the PET, but acetaldehyde can not only be produced during polymerization but also during the bottle making process. When acetaldehyde is present in large amounts in a PET bottle it gives a noticeable difference in taste compared to one that does not have as much.

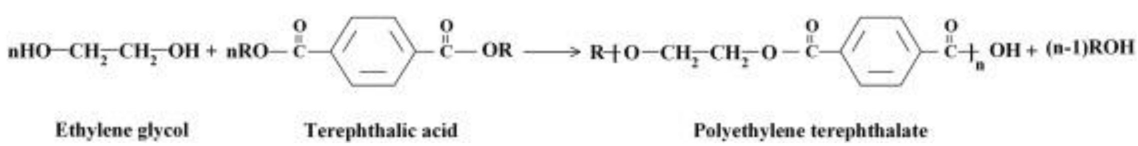

Figure 7. Reaction that forms Polyethylene Terephthalate

Once the plastic has been made, the plastic is checked to make sure that it is appropriate for use. These tests are done to ensure that the bottles are impermeable by carbon dioxide, as well as seeing factors like transparency, gloss, shatter, resistance, thickness, and pressure resistance. Bottles are then blow molded into their shapes and shipped off with the logo of choosing by the manufacturer.

PET bottles break down into microplastics because of the strong primary bonding but weak secondary bonding. Physical wear and tear can hardly be seen on plastic bottles from daily use, but if one tries to break it, they will find that it is not difficult. All the visible breaking down of the bottles are in the secondary bonding. The real strength however is in the primary bonding of polyethylene terephthalate.

The primary bonding of PET is covalent. There are covalent bonds binding 2 carbon atoms which have two hydrogen atoms each. This is the repeated unit which makes the long chains which form polyethylene terephthalate. The bonding between these chains is weak van der Waals bonding. This makes the secondary bonds break rather easily, leaving microplastics held together by its strong covalent bonding.

Proposed Materials Solution

My idea comes from a study done which uses physical and chemical changes as well as biological changes to the material to allow it to be more biodegradable. This study introduced the common problem with improving materials selection for a product as popular as drinking bottles, the economic aspect. Most companies are unwilling to lose money on this issue that arguably most people don't really care all that much about. So, it is hard to justify expensive, and time-consuming changes to the materials processing which is done in making PET bottles.

The study mainly focused on making used PET bottles biodegradable, but I think that the changes made would be able to be split up so that some of the process could be done when the bottle is made. The people crushed PET bottles and covered them with liquid nitrogen. Then various samples were prepared with streptomyces (a bacteria), and the samples were spun in tubes for days. If the PET was infused with nitrogen before production into bottles, then the bottle would appear to be the same but be prepared for biodegradation more effectively.

The study followed a process of five steps: 1st the preparation of pure bacterial strain, 2nd the treatment of diluted PET sample in culture medium with streptomyces species, 3rd the extraction of residual PET and determination of degradation percentage, 4th the analysis of metabolite by GC-MS equipment to identify products of biodegradation, and 5th the SEM analysis on PET film exposed to biodegradation by streptomyces bacteria.

The study concluded:

> "PET samples were cut, grinded and classified into four different particle sizes. In each experiment, 50 mg of PET powder were incubated in a culture medium containing 20 mL of a mineral medium and 0.5 mL suspension of *Streptomyces* species at 28 °C at 120 rpm for 18 days. The highest biodegradation value was obtained as 68.8% for particle size of 212 μm on 18th day. Also GC-MS analysis of the sample having highest degradation ratio, showed that bacteria degraded PET powders into less harmful components with low carbon numbers."
>
> The results are pictured below in Fig. 8

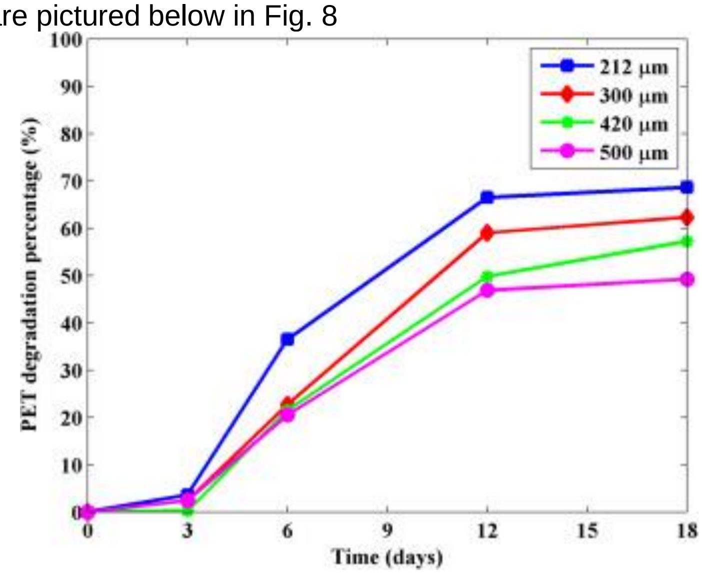

Figure 8. Degradation Percentages for Different Particle Sizes with respect to Contact Time with Streptomyces Species

The materials properties are changed by this idea by making the microparticles break down into less harmful components. The PET was crushed into powder and then injected with the bacteria to help it break down into smaller sized microplastics. This brought about a 68.8% decrease in particle size after making the proposed changes. This would lead to 1: less microplastics sticking around PET bottles and 2: the microplastics and other particles which remain would be less harmful to the environment.

Anticipated Challenges and Impact

The major technical challenges associated with this idea are 1: the cost, 2: the time, 3: the amount of work. This study seems practical when it is conducted in a lab by a team of scientists. But it may be unreasonable to assume that large drink brands would consider putting this much work in for a 68.8% decrease in particle size. As well as the fact that this idea takes time and costs money. I am not aware of what kind of facilities drink brands have, but it may again be unreasonable to expect them to have a lab prepped with all the instruments used in the study. And the last bit of the problem is the amount of time that it takes. This study took multiple weeks, also because the scientists were looking to see how the results would change over time. They found that the best results took 18 days to achieve. This would mean a lot of time invested, again, for not that big of a difference.

A proposed solution for some of these problems would be for separate recycling or environmental science companies to be hired by the drink makers to take care of the bottles after they are used. Instead of shipping recycled plastic bottles to a landfill or incinerator, they could send them to these laboratories where they would undergo this process to be biodegraded more efficiently.

The economic issues were explained a bit above, but I feel that the cost and time used to complete this process would turn a lot of companies off. Over time, recycling has become less appealing to companies precisely because of the cost involved. This process may seem like too much of a hassle compared to dumping it into a landfill and leaving it for future generations to deal with. Economically however, it may happen that people who currently use reusable bottles or refuse to buy PET bottles because of the environmental impact will begin to buy them again after they learn that they are now less harmful.

Currently, it is the responsibility of the consumer to first place the finished bottle into a recycling bin instead of a garbage can. Already there are many people who take that first step wrong. After that, it is up to whoever owns it to see that the product is correctly sent to a recycling facility. If the recycling facility is still in business and properly recycles, then it is good enough that bottle might become an article of clothing. There is also the case, however, of places like my high school which appear to recycle and then don’t. If the post-mortem process for PET bottles was handled in such a way as this report suggests, and companies took on the idea, then maybe more and more PET would biodegrade effectively instead of forming microplastics.

Behaviorally this change would positively affect consumers as mentioned above. The consumers would feel better about using PET bottles if they knew that they could not biodegrade well and not form microplastics after use. I would predict more purchases of PET bottles and therefore more revenue for beverage companies if this change were to be made to PET bottles.

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