Plastic fantastic? Or how a microbe near you will help shrink the plastic mountain.

Think about how often you pry open a plastic container filled with your favorite snack, and what about all of those plastic bags you carry home after shopping for groceries. Plastics are without doubt present almost anywhere you look. It is surely a very useful material. But as you might have guessed from the title I will not tell the story about the greatness of plastics. I will rather tell you about the problems arising from it. And a possible solution – probably a smaller one than you imagined!

Synthetic plastics are among the largest molecular structures, composed of a single molecule, ever produced by mankind. This means that a very large object made of plastic, say the body of an automobile, in theory might consist of a single molecule. This is possible since plastics are polymers, long chains of monomeric constituents. This means that they will continue to grow indefinitely until they are stopped by either adding chemicals or choke the supply of monomers. From some types of plastics, such as polyethylene (PE), a great number of side-chains sprout from the main chain. This is one of the factors which explain why the plastics come in so many forms and characters. Another factor is how flexible the chains are, which depend on the structure of its monomeric constituents and if any chemical additive has been used in the production. These are just a few of the reasons behind the vast diversity of plastics.

Plastics are not the only polymer in existence. Nature has since the beginning of life employed the characteristics polymers. Proteins and carbohydrates such as starch are polymers. Even DNA, the so-called blueprint of life, is a polymer. These natural polymers do generally biodegrade under favorable conditions in nature. Hence there are no huge piles of meat of mountains of potatoes lying around – they will eventually all break down. This degradation is in part due to hungry animals passing by but also heavily dependent on fungi and bacteria. Also known as the microbiome. These small organisms can be found almost anywhere at almost any time and will without hesitation attack and break down the polymer to access its stockpile of cellular building materials and energy. As a result they grow in numbers. And grow. And grow. Finally all biodegradable material is converted to microbiological biomass. This process is called mineralization.

- *But why can’t plastics be degraded by the microbiome?*

It is all about structure!

While it’s true that plastics in most cases contain the same building blocks as organic polymers, they have several other characters which make it hard or even impossible for the microbiome to attack it. The attack I’m speaking of is mediated by a weapon, a weapon with a great reputation when it comes to speeding up chemical reactions; the enzymes. Enzymes are large molecular machines produced by living cells and microorganisms. They are of great importance in a multitude of biological chemical reactions. Some of these reactions involve

breaking down larger molecules for food. Every enzyme has a favorite target molecule, or food, also called its specific substrate. Some enzymes break down the protein in meat, other enzymes the starch in potatoes. And as science has started to show us – some enzymes might fancy eating plastic.
But this appetite for plastics is, as I just mentioned, depending on the type of plastics. Most conventional plastic are not readily munched on by an enzyme. A plastic which chain is completely consisting of coal-to-coal bindings, and whose tightly packed chain producing a large molecular size, is very unappetizing. However, a chain with different molecules such as oxygen and nitrogen in it is easier for the enzyme to attack.

- *But where might these types of chains be found?*

In biodegradable bioplastics!

Bioplastics is a new type of plastic material which is based on natural raw materials. Since it is based on a living coal source instead of a fossil coal source it can be called a renewable material – a highly attractive treat in today's dwindling oil age. There are several bioplastics which could potentially replace our current conventional plastics. Examples range from poly-lactic acid made by fermenting corn to plastics based on starch from potatoes. One prime example of bioplastic, which is both made and degraded by microbes, are the poly hydroxyalkanoates, PHA: s.

PHA has existed inside the cell wall of many bacteria since a vast amount of time, but has only quite recently been discovered. These organisms store excess energy in times of scarcity in the form of compact particles – granules – made of this bacterial polyester. First discovered by Maurice Leoigne in 1926, one type of PHA has awakened a huge interest in the potential of uses of bacterial polyester. Poly hydroxybutyrate, PHB. The reason for this interest is centered on the characteristics displayed by PHB. It really puts up a match against the current sweet-heart of conventional plastics – polypropylene. At the same time PHB plastics is readily biodegradable in nature, so whenever you are done with your water bottle and have no trash can nearby, then feel free to dump it on the ground. The soil bacteria will even thank you for it by increasing their biomass!

- *But what is the point of using these plastics?*

No more worries about oil and trash!

One of the greatest advantages of biodegradable plastics is the opportunity to mix plastics with food and compost them together either to provide new soil or bioenergy in the form of bio-gas. A second advantage is the lack of dependency of oil. Oil, as a non-renewable resource, is problematic for many reasons. Projections seem to indicate that the availability of oil is diminishing. Thus the price of the oil we find will probably increase heavily – and the price of oil-base plastics accordingly. To be able to develop these new plastic materials based on renewable resources is a very good idea. The third advantage of bioplastics is a simple one. Most plastic pollution in the world is in part resulting of everyday plastic packaging. This plastic will not be collected for waste management easily. But bioplastics will simply shrink away. PHA will, for example, last only 6 weeks on the ground.

-But what about the organisms responsible for creating these great advantages? They deserve an ovation!

They sure do!

The key players of plastic degraders are found in the fungi and bacterial domains of microorganisms. Fungi are worth mentioning first. Their main mode of action is to colonize and drill through the plastic with their hyphae. This is in a sense reminiscent of how wood is broken down in nature. Powerful enzymes are released by the fungus which hacks away on the polymer chains. Bacteria are nonetheless also very important for plastic degradation. The bacteria, like the fungi, use enzymes as a main tool for energy extraction from plastics. These enzymes can either free-float inside and outside of the cell or, even more interestingly, be part of the cell membrane and attach itself to a piece of plastic before starting to break it down. Enzymes break down the polymer either by a hydrolytic reaction, which add a water molecule to a chemical bond in the polymer, or by oxidation. The hydrolytic reaction demands presence of water while the oxidation requires air. These conditions determine which kind of microorganism uses these enzymes. Fungi can only perform the degradation where there is ample supply of air, while some bacteria do not require it.

- *What now?*

We just have to wait for compostable packaging!

Plastic is still fantastic, and the world seems not to use it any less these days. Fact is, there has been a steady increase of the consumption of plastics. This increase doubtlessly seems to be the result of an increase in worldwide consumption. More stuff – more plastics. Not denying that plastic is a very useful and important material, a new paradigm of materials could be on the everyday-horizon. The European Union has made it clear that its member states are supposed to reduce the amount of plastic waste and prohibit dumping of waste in landfills. This is a good idea since the greenhouse gasses which are emitted from the packed landfills are problematic. However, biological treatment of waste in compost or anaerobic bioreactors is a method of choice. Furthermore, if all plastic packaging would become biodegradable, the average waste stream from any household would decrease since plastics are a big part of the waste involved. These materials will hopefully be more available in the future. And they will cater to the diet of many a microbe. This might be a way to shrink the plastic mountain.

/Johannes Pohl

For further reading, see:

Pohl, J. 2013. I plastbergets botten: mikroorganismernas roll för tillverkning och nedbrytning av plaster.