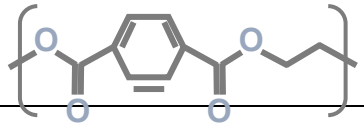
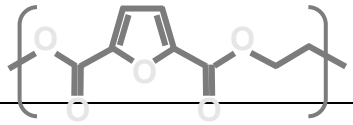
PEF - the polymer for the future

1 Intro to PEF

Polyethylene 2,5-furandicarboxylate, or PEF for short, is a novel polymer with a chemical structure that has a high resemblance to that of PET. It is produced by polycondensation of the monomers FDCA (2,5-furandicarboxylic acid) and MEG (mono-ethylene glycol), analogous to the polycondensation of the raw materials used to produce PET. The PEF polymer itself has been known for a long time, but has never been produced at large scale or applied commercially as there were no economically viable production routes to manufacture the key monomer FDCA. Currently, Avantium and a number of other companies are working on new methods of producing FDCA, which will enable PEF to become a new widespread polymer for the future.

2 Basic properties

The Furan ring in this polymer introduces a 'kink' into the polymer chains, which makes them less mobile compared to the straighter chains of PET and affects its properties significantly. In addition, the dipole in the furan ring introduces attractive forces between the molecules, further reducing mobility. Some of the resulting effects are a higher glass transition temperature and a higher modulus relative to PET. A further consequence is a higher barrier against gases, this makes PEF a very interesting material for packaging applications.

Property[1] [2] [3]	PET (Amorphous)	PEF (Amorphous)
Molecule		
Density	1.36 g/cm^3	1.43 g/cm^3
T_m	250-270°C	210-230°C
T_g	~76°C	~88°C
E-modulus	2.1-2.2 GPa	3.1-3.3 GPa
Yield strength	50-60 MPa	90-100 MPa
O_2 permeability	4.7 – 7 .4 cc*mm/(m2*24h*bar)	0.4 – 0.7 cc*mm/(m2*24h*bar)
CO_2 permeability	20 – 30 cc*mm/(m2*24h*bar)	1 – 3 cc*mm/(m2*24h*bar)

[1] S. Burgess et Al – 2014 -Oxygen sorption and transport in amorphous poly(ethylene furanoate) – Polymer
[2] Van Berkel et al - 2018 - Biaxial Orientation of Poly(ethylene 2,5-furandicarboxylate: An Explorative study – Macromolecular Materials and Engineering
[3] MOFFIT, Ronald; DUSKAUR, Jasmeet; FREEMAN, T. Edwin; KRIEGEL, Robert; SHI, Yu; MORALES, Marlon Salvador; NAGHAL, Vidhu - BARRIER ENHANCED PET MULTILAYER CONTAINER - WO2016/130748

Many, if not all, of the relevant manufacturing processes that are under development aim at using plant-based resources (e.g fructose) as a feedstock. When plant-based MEG is used with FDCA, PEF is a fully bio-based polymer, making it an excellent candidate for the bio-based economy.

In many regions around the globe, recyclability of everyday materials is of prime interest and industry and government organizations are setting high recycling targets. For example in the EU, by 2030 all beverage bottles will need to contain at least 30 % of recycled material[4]. Obtaining high quality PET waste is essential to achieve those recycling targets but is also notoriously difficult. One of the main challenges is that most polymers used in combination with PET hamper its recyclability. A typical example is a multilayer bottle that uses Polyamide as a barrier layer. The Polyamide disturbs the output of a mechanical recycling process and induces haze in the r-PET. Less than 2% of Polyamide in a PET waste stream can cause so much haze that the r-PET is rendered unusable (a bottle with 5% polyamide as barrier layer is considered not recyclable). PEF is chemically so similar to PET that it blends well during the recycling process, forming a co-polymer and therefore causing very little disturbance in the resulting r-PET; a PET/PEF mixture will stay almost completely transparent with up to 5 % PEF. This makes PEF highly suitable for combinations with PET without affecting its recyclability. PEF is a polyester, which can also be recycled solely by itself using technology used for PET both today and in the future.

4 Product examples

For small CSD bottles, the gas barrier requirements are too high for PET to meet them alone. Currently, a polyamide barrier layer is added to achieve the required performance; however, as described above, this makes the product unrecyclable. A potential solution for this is a PET-PEF-PET multilayer structure, with a PEF layer only respresenting a few percent of PEF, creating a product that will be recyclable in the current PET waste streams; The amount of PEF will be diluted so much that its concentration is then far below the threshold whereby it may cause detectable differences in the properties of r-PET.

There is also large potential for PEF in high barrier flexible packaging. Currently, such films consist of many layers composed from different types of polymers. PEF can be bi-axially oriented to form BO-PEF (just like BO-PET). This film has the potential to simplify the existing structures, combining different functionalities in only one polymer layer (such as gloss, strength, barrier, etc.). Although the recycling of such films is still in its infancy, one can make the general statement that a simpler structure will result in a simpler, more easily recyclable film.

5 Summary

To summarize, PEF is a very versatile and promising polymer for the future. Avantium and several other companies are working on processes to make it commercially viable and it is only a matter of time before its entry into the market. The benefits are too many and too obvious for it to fail, and it fits perfectly alongside PET as a recyclable raw material in the bio-based economy.

6 About Avantium

Avantium is a leading technology development company and a forerunner in renewable chemistry that develops novel technologies based on renewable carbon sources as an alternative to fossil-based chemicals and plastics. The company currently has three technologies at pilot and demonstration phase. The most advanced is the YXY® plant-to-plastics–technology that catalytically converts plant-based sugars into a wide range of chemicals and plastics, such as PEF (polyethylene furanoate). Avantium has

[4] https://www.consilium.europa.eu/en/press/press-releases/2019/05/21/council-adopts-ban-on-single-use-plastics/

successfully demonstrated the YXY Technology at its pilot plant in Geleen, the Netherlands. The second technology is the Dawn Technology™ that converts non-food biomass into industrial sugars and lignin. In 2018, Avantium opened the DAWN pilot biorefinery in Delfzijl, the Netherlands. The third technology is called Mekong and catalytically converts industrial sugars to plant-based MEG (mono-ethylene glycol). Avantium is currently building a new demonstration plant for Mekong with an opening planned in November 2019. Next to developing and commercializing renewable chemistry technologies, the company also provides advanced catalysis R&D services and systems to customers in the refinery and chemical industries. Avantium works in partnership with like-minded companies around the globe to create revolutionary renewable chemistry solutions from invention to commercial scale.