PEF as a multilayer barrier technology: a sustainable way to enable long shelf life in PET bottles

Francesco Acquasanta, Roy Visser, Bart Langius
Avantium, Amsterdam, The Netherlands

Avantium, Renewable Polymers, a 100% subsidiary of Avantium, plans to build a flagship plant for the production of FDCA (furan dicarboxylic acid), a monomer for high-performance polyesters such as PEF (polyethylene furanoate). The plant, which is aimed to be on-stream at the start of 2023, will have a nameplate capacity of 5 metric kilotons per year and be located in Delfzijl, the Netherlands. Avantium is already producing FDCA and PEF at a smaller scale from its pilot plant in the Netherlands and is using this material to accelerate the market introduction of various high-value applications, including those in packaging. Made from renewable resources, compatible with existing recycling equipment and with outstanding barrier properties (approximately 10 times better O₂ and 20 times better CO₂ barriers with respect to PET /1/, PEF is full of potential promise: not as a replacement for PET, but as a side-by-side complementary technology, enabling a full polyester solution for applications where both the performance and sustainability of the incumbent is not sufficient.

PEF, a performance material
Avantium currently offers a 100% plant-based, PEF grade for development in application areas such as rigid and flexible packaging, injection molded articles, films and fibers. This resin offers outstanding barrier performance, coupled with balanced thermomechanical and processability properties. Avantium’s PEF is compatible with PET recycling assets, can be identified and sorted using near infrared technology and can also be recycled as a separate stream. When PEF is processed as part of the PET recycling stream, even 100% PEF bottles will have no negative impact on haze, color and other properties of the resulting rPET products at market penetration levels of at least up to 2% PEF into the rPET /2/.

Barrier requirements in rigid packaging
PET’s success as the material of choice for beverage packaging is due to its ideal combination of performance,
Co-injection processing of Avantium PEF on Husky’s latest multi-layer technology is straightforward, and similar to the processing technology of PET. Several combinations were injected mid-layer centered or biased towards center, including different percentages of PEF, in open and closed dome structures. The material posed no limitation for optimal processing, therefore we were able to deliver best-in-class material distribution, positioning and consistency expected of Husky co-injection platforms.

The ease of processing of Avantium’s PEF material on Husky’s multi-layer systems creates an exciting new opportunity for the optimization of package performance and achieving the greatest benefits from this promising barrier material.”

Advantages of PEF as barrier material in multilayer PET containers

Avantium’s PEF offers several advantages when compared to incumbent barrier materials, and positions itself as a valid alternative due to its unique properties:

- Good passive barrier for both O₂ and CO₂
- Excellent surface compatibility with PET, resulting in a low tendency towards delamination
- Far more compatible with PET than polyamides in general and in particular during the recycling process. In the case of non-complete barrier layer recycling during the sorting step, the remaining PET will not deteriorate the quality of the resulting rPET resin.

Co-Injection molding of PET/PEF/PET multilayer Preforms

PEF can be easily processed in existing equipment used today to produce multilayer preforms, as has been demonstrated on multilayer injection systems produced by Husky.

The use of a suitable PEF grade from Avantium together with the right injection molding know-how and equipment will allow for a broad layer positioning and distribution to be obtained in the preform, which will maximize the barrier performance benefits that PEF can bring to a PET bottle.

An aspect that is important to consider is the preform/bottle design combination. PEF is characterized by a high natural stretch ratio so it therefore requires more stretching than PET to undergo strain hardening and result in optimal mechanical and barrier performance. Within the design space of PEF, it is advised to choose a total stretch ratio of 1.2 or higher. Positioning the PET layer closer to the inner surface of the preform (core biasing) is also a way to increase the (radial) stretch ratio PEF will experience during blowing and therefore further increase strain hardening, promoting strain induced crystallization and hence peak barrier performance.
During blowing trials the PEF content didn’t influence processability of the preforms, and with the same process and set-up we were able to produce bottles with similar material distribution and dimensions.

Performance of PET/PEF/PET multilayer bottles

Multilayer preforms containing PEF were stretch blow molded to produce 500 ml bottles using standard PET bottle processes and geometries, and resulted in similar material distribution and mechanical performance (Figure 1) as a monolayer PET reference. Once stretched, a multilayer bottle with PEF also shows no appreciable color or haze differences when compared to monolayer PET.

If the dimensions and mechanical performance of a multilayer PET/PEF bottle are very representative of a monolayer PET reference, the advantages truly shine when it comes to shelf life. Increasing the shelf life of the package whilst keeping at least the same mechanical performance, PEF will enable further light weighting and therefore also the use of less rPET to achieve recycled content targets. Enabling entry into the PET recycling stream also means that cascade recycling, incineration or even landfilling can be circumvented. PEF/PEF multilayer bottles that enter the PET recycling stream will be able to undergo all steps of mechanical recycling, whereas current barrier materials require the highest efficiency in separation steps so as to not contaminate rPET. Even if separation of the barrier layer is not complete, relatively large quantities of PEF (up to few percent) remaining in PET will hardly have any effect on the color, haze and processability of the rPET produced by a mechanical recycling loop /2/.

Sustainability of PEF multilayer technology

The use of PEF as a multilayer barrier technology will be a valuable solution in the PET bottle design toolbox to achieve sustainability targets for both reduction of material and improved recyclability. Increasing the shelf life of the package whilst keeping at least the same mechanical performance, PEF will enable further light weighting and therefore also the use of less rPET to achieve recycled content targets. Enabling entry into the PET recycling stream also means that cascade recycling, incineration or even landfilling can be circumvented. PEF/PEF multilayer bottles that enter the PET recycling stream will be able to undergo all steps of mechanical recycling, whereas current barrier materials require the highest efficiency in separation steps so as to not contaminate rPET. Even if separation of the barrier layer is not complete, relatively large quantities of PEF (up to few percent) remaining in PET will hardly have any effect on the color, haze and processability of the rPET produced by a mechanical recycling loop /2/.

Conclusions

The market introduction of PEF should be considered good news for PET packaging, as it enables improved barrier performance whilst maintaining all other key properties. Avantium’s PEF, slated to be commercialized in 2023, can be used as a barrier material in multilayer PET rigid packaging and offers a unique combination of easy implementation, robust processing and performance and outstanding barrier. Multilayer bottles using PEF will not only enable shelf life extension and light weighting possibilities, but also represent an opportunity for polyester packaging to reach new application areas, such as small containers or sensitive products, where PET alone cannot go - all without sacrificing recyclability or sustainability!

Acknowledgements

The support of Husky for the preform production and the know-how of co-injection is greatly appreciated. The bottle blowing and bottle testing was done in collaboration with Logoplaste Innovation Lab.

Fig 1: Performance of 500 ml flat base, 19.7 g bottle, courtesy of Logoplaste Innovation Lab. The max top load in N on filled containers is within the specification, even higher for the sample with 10% PEF.

Fig 2: OTR data and Barrier improvement factors of 500 ml flat base, 19.7 g bottles, courtesy of Logoplaste Innovation Lab. The OTR is measured with the sensor dots method.

Fig 3: (a) Effect on appearance of PEF and MXD6 when blended with PET, as could happen during recycling of multilayer if barrier layer is not efficiently separated. (b) Data on Ab* and Ahaze (calculated respect the average values of 100 wt% PET) and the picture of plaques show, the PEF has hardly any impact on appearance, while MXD6 give significant haze and yellowness.