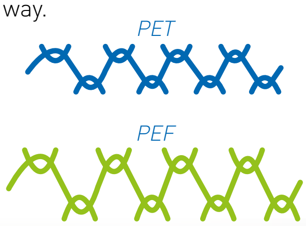
PEF bottle blowing

Since its establishment in October 2016, Synvina has laid a solid foundation for the establishment of a 50,000 tonnes value chain for 2,5-furandicarboxylic acid (FDCA) and poly(ethylene 2,5-furandicarboxylate) (PEF), building on synergies between its two parent companies Avantium and BASF as well as its partners. Important milestones have already been reached, amongst which a grant of 25 million EUR from the European Joint Undertaking on the Bio-Based Industries (BBI) for these efforts and interim approval of the European PET bottle platform for market introduction of Synvina's PEF at this scale.

PEF is chemically similar to polyethylene terephthalate (PET) while offering improved gas barrier properties and mechanical properties, which can allow light-weighting or redifinition of many packaging applications. The nature of these differences in amorphous and oriented PEF was previously explained in Avantiums cover article in issue 04/2015 of bioplastics MAGAZINE. The article furthermore shows that PEF can be used in both rigid and flexible packaging for beverages, food as well as personal and home care products. Bottles however remain one of Synvina's focus applications, and this article aims to present the how-to on PEF bottle blowing in practice.

Selecting a PEF grade

For polyesters, the intrinsic viscosity (IV) is one of the basic features defining a grade, usually balancing the ease of melt processing (flow and temperature) and favorable mechanical properties for the intended end-use. PEF's IV can be measured using the same standards as PET and other polyesters, such as PBT or co-polyesters, but the values have different meanings. Typically, the IV range for PEF resin for the targeted applications is higher than what is common for PET. The main reason is that PEF's polymer chains form fewer entanglements, which give the material strength during hot drawing and product end-use. Therefore, PEF requires longer polymer chains and thus a higher IV to reach the same amount of entanglements as PET. This provides some challenges in resin production, but Synvina has developed various processes to produce high IV PEF grades in a cost-effective way.



Schematic of a PET and a PEF polymer chain having 8 entanglements with other chains, highlighting a longer distance between entanglements for PEF and thus a longer chain length

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Preform injection

PEF resin can be processed in various polymer extrusion and injection molding equipment at temperatures from 240 °C up to over 300 °C. Melt processing equipment that are commonly used for PET, other polyesters or polyamides is preferred, since screws designed for polyolefins and other polymers may lead to inhomogeneous molten polymer or inconsistent flow. Just as PET, PEF requires drying prior to melt processing to a maximum moisture content of 50 ppm to avoid excessive IV loss, such drying can be done using conditions similar to those used for PET. The typical melt processing behavior of PEF depends on the PEF grade used;

- PEF's melting point is typically lower than PET and can vary between 205 °C and 235 °C, while its crystallinity is comparable to PET, varying between 35 % and 60 %.
- PEF's melt viscosity is similar PET of the same IV at around 270 ± 10 °C, while molten PEF is less viscous at higher temperatures and more viscous at lower temperatures.

Due to its higher viscosity at low temperatures, it is important to add sufficient heat in the feed zones to allow the material to be sufficiently molten before it experiences the shear forces exerted by the screw in the melt compression section. This avoids overheating by friction in those zones. Examples of typical temperature profiles are given in the table below. When injecting preforms, it is important to ensure that they are fully filled, homogeneous and free of gas pockets, particles, and internal stress. Since PEF crystallizes slower and has a higher glass transition temperature, preforms may be ejected at higher temperatures and cooling times can be reduced, increasing throughput.

Stretch-blow molding

For a given bottle design, PEF preforms are typically chosen to be somewhat smaller than PET preforms to achieve higher stretch ratios. Since PEF has fewer entanglements the polymer chains can undergo more orientation, which should be used to develop crystallinity and maximize bottle performance. The stretch ratios employed for PEF bottle blowing are usually at the upper limit of what can be blown with PET without stress-whitening ('pearlescence'), or even higher. Despite the difference in glass transition temperature PET and PEF are blown at comparable temperatures to maximize PEF's properties. PEF preforms are usually thicker than PET preforms, to compensate for the smaller size. This results in a different optimal heating profile, but the overall heat consumption is comparable. Commercial reheat additives can be used in PEF to optimize preform temperature distribution and energy consumption.

Bottle properties

With the abovementioned slight adaptations to the general understanding of PET bottle production, brand owners, converters and bottlers can produce PEF containers that can offer shelf-life improvement without the need for investment in barrier equipment. An example of PET bottle properties compared to those of PEF bottle properties in the same shape is shown in the table below. Clearly the CO_2 shelf life improvement of up to 5x stands out, while the drop test resistance of PET is maintained. The oxygen barrier was not measured in this example but typically yields 8-10x the shelf life of unmodified PET. This can enable long-term shipment and storage while maintaining product quality in even the smallest of bottles.

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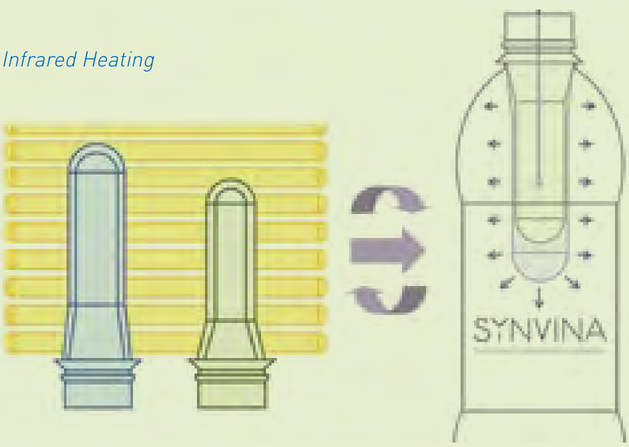
Conditions	TFeed → Die / Nozzle (°C)			
	Zone 1	Zone 2	Zone 3	Zone 4
Example 1	270	260	250	250
Example 2	275	265	260	260
Example 3	285	275	270	270
Example 4	285	280	280	280

Infrared Heating



Bottle volume (oz / mL)	8 / 237	
Material	PET	PEF
Weight	13	14
Drop test @ 1.8m	Pass	Pass
Burst test 30s @ 14 bar	Pass	Pass
3.2 Vol. CO2 Thermal stability, fill drop after 24h @ 38°C (%)	-4	-3
4.2 Vol. CO2 Thermal stability, fill drop after 24h @ 38°C (%)	-5	-5
3.2 Vol. CO2 Shelf life, 90 days extrapolated to -17.5% (wks)	7	26
4.2 Vol. CO2 Shelf life, 90 days extrapolated to -17.5% (wks)	6	16