Beverage containers made of recycled PET

Characteristics, processability and possible uses of rPET

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1. Starting point

As a member of the European Circular Economy Stakeholder Platform, Krones is an advocate for keeping plastics used in packaging in a closed loop.[1] Our technologies for the manufacture and further processing of recycling PET (rPET) are being used by customers all over the world – and some of them for several decades. At our plants in Flensburg and Neutraubling, we also work in our own laboratories to analyse and test the material characteristics, possible uses and processing conditions of various types of plastics.

We would like to share the most significant findings gained through our research and laboratory work with rPET and post-consumer recyclate (PCR) in this whitepaper – and thus make a contribution to utilising the sustainability potential offered by rPET on a wider scale.

[1] https://www.krones.com/en/company/press/krones-joins-the-eus-circular-economy-initiative.php

2. Material characteristics of rPET and their effects on bottle production

Recycling material for preform and bottle manufacture can – to varying degrees – exhibit the following three characteristics:

a) **Yellowing:** A progressive yellowing of the PET material may occur through the melting processes and, in particular, due to high levels of contamination in the recycling flow. The yellowing can be partially balanced out with a minor blue colouration.
If the colouration is consistent, this will not be a problem for the blow moulder. An uneven colouration however will lead to an uneven material distribution – both within a container and from bottle to bottle.

b) **Black specks:** Foreign matter that chars during the melting process applied in recycling or injection moulding appears as small black specks inside the preform wall. They can lead to localised over-tempering. The consequences range from very thin or weak material in the container wall up to the bottle bursting.

c) **Inhomogeneities (IV fluctuations[2]):** In the recycling process, the IV value of the incoming material can be increased with Krones MetaPure technology. However, the following applies: If incoming materials with different IV values and copolymer parts are mixed, this can only be partially balanced out. A possible consequence of this is once again an uneven material distribution – as before, both inside the same container and from one bottle to the other.

[2] IV = intrinsic viscosity; the IV value is a significant marker of PET quality characteristics. It is measured in decilitres per gramme (dl/g) and is a measurement showing the chain length of the PET molecule.

3. Handling of rPET in the Krones Contiform

No major problems will occur during the processing of rPET as long as the material is supplied in a consistent quality. The Krones Contiform stretch blow moulder also has a range of functions to deal with fluctuating material characteristics:

a) **Yellowing:** Colour fluctuations in the preform flow, that occur slowly and result in varying heat absorption, are compensated by the heating module controller. If the colour fluctuations are too big to be automatically balanced out, the different colourations can be detected with an inspection camera and affected preforms can be rejected.

b) **Black specks:** Specks measuring 0.5 millimetres or more are detected by the 360° side-wall inspection unit of the PET-View preform inspection system. The blow moulder can also detect holes formed as the result of black specks. However, if very small holes form due to local overheating, it is possible that these will not be detected in some cases.

c) **Inhomogeneities:** Deviations from a required material distribution can also be measured with PET view and flawed bottles rejected accordingly.

4. Incoming goods inspection as the basis for a reliable process

Generally speaking, goods receiving inspection is of fundamental significance. On the one hand, so that the blow moulder does not need to take on the role of a machine for sorting out poor rPET quality. On the other, because the appearance of too many gaps in bottle production can lead to further implications for production. To avoid both, the quality of the incoming preforms should be checked, either through a visual inspection or, for example, by randomly checking the IV value, the colour consistency and the moisture content.

Preform octabins should be ideally processed in the same order they were produced. By doing so, subtle material changes originating from injection moulding production will arrive at the blow moulder at a slow enough pace, thus allowing the heating module controller mentioned under point 3a) to balance out the deviations.

4. Incoming goods inspection as the basis for a reliable process

If the octabins are not processed in the order that they were produced, there is an increased risk that preforms with widely varying infrared absorption characteristics all reach the blow moulder at the same time. In extreme cases, the differences are so big that the control system of the heating module can no longer compensate for them. As a result, adjacent preforms with greatly varying temperature profiles are transferred from the oven to the blowing stations. The heating module controller cannot balance out such preform mixes. The preform temperature is regulated by the controller for the entire oven, allowing between 300 and 400 preforms to be heated simultaneously, depending on the machine size. In other words: The linear oven system requires a consistent thermal absorption of the preform flow without erratic changes, both for rPET and for new PET. If this is not the case, the rejection rate increases and this creates more work through the emptying of the rejection bins and, most importantly, pushes up production costs.

5. Determining the quality of rPET

Recycled PET is awarded a good quality when its most important material characteristics are the same as those of virgin PET. The following are seen as quality criteria:

- The IV value (intrinsic viscosity)
- Degree of contamination
- Acetaldehyde content, amount of other migrating substances included
- Moisture content
- Material staining

The specifications provided by the RAL Quality Assurance Association, which recommends feasible maximum values, can be used as a guide.

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6. rPET quality and bottle performance

If the material is of consistently good quality, there are no recognisable major differences in bottle performance compared to virgin PET. Since the characteristics of rPET can be raised to a similar level as those of new PET during the recycling process, the bottle performance is comparable as regards CO_2 impermeability, stress cracks, top load, bursting pressure and thermal stability. However, if the yellowing is inconsistent, there are too many inhomogeneous areas or the number of black specks exceeds the limit value, this may lead to fluctuations in bottle performance. It is thus essential to ensure that the quality is good before the preform reaches the blow moulder.

In container/preform combinations which already push the specification limits, the anticipated rPET quality fluctuations may lead to more problems than would occur if virgin PET were to be used. Bottles with high stretching ratios could burst more frequently for example. This should be taken into consideration during the design and development phase.

7. Possible rPET ratios in a bottle

The ratio with which recycling and virgin PET can be combined in a container depends on:

- The quality of the post consumer recyclate used and
- the corresponding preform and bottle specifications.

Very high proportions of PCR can be run with clean, monofractional recylate without any problems – and, if the preform and bottle specifications facilitate it, even up to 100 percent.

It is therefore important to perform sufficient testing, optimally on a large scale on the line. A frequent side effect of the use of rPET is that there is a slight increase in the rejection rate, which sometimes can be traced back to the aforementioned, unavoidable black specks and inhomogeneous areas.

8. Design for recycling

Design for recycling is divided into two main sections:

a) Design of the bottle to suit the recycling process
b) Consideration of the material characteristics and the quality of the recycling material

Regarding point a), decisions made early in the design process can have a significant impact on whether a bottle can be returned to a high-value use, such as producing a bottle again.

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8. Design for recycling

Designing primary packaging involves the selection of packing materials, colours, barrier materials and additives, caps, printing colours and adhesives. All of the added materials have an influence on the recycling flow and their implications can be split up into three categories: Full, limited and low compatibility with the recycling process.

This is why the EPBP design guideline recommends selecting materials, which

- can be **recycled together** or
- have **different densities** and can thus be easily separated.

The cleaner and more monofractional the incoming material is

- the higher the output quality of the recycling material,
- the fewer problems arise in the blow moulder,
- the better the bottle performance and
- the better it can be recycled again.

You can find more details on this in the Krones “Design for Recycling” guideline or on the European PET Bottle Platform (EPBP) website: https://www.epbp.org/design-guidelines

9. Food-grade compatibility of rPET

All technologies for the production of food-grade recycling material must be certified in the EU by the EFSA or, for the USA, by the FDA. Krones MetaPure technology has both certifications.

To achieve EFSA certification, a procedure must be able to provide a specific decontamination and cleaning performance. If food packaging is made of recycled plastic, the following obligatory origin quotas shall apply:[3]

- 95 percent of the recycling material must originate from food applications.
- A maximum of 5 percent of the recycling material may originate from non-food applications.

The adherence to these quotas must be regulated and monitored in the recycling process. The responsibility for the food-grade compatibility of rPET is thus in the hands of the material manufacturers and recyclers.

The EU also regulates the maximum permissible migration values that an end product, still water for example, may have after 365 days at a storage temperature of 25 °C.

[3] Other values may apply in other countries depending on their regulations.

9. Food-grade compatibility of rPET

If inadequate rPET is used, the stretch blow moulder will not be able to prevent a possible contamination of the subsequent product, as it does not change the composition of the material and thus also not the food-grade safety of new or recycled material.

The Contiform can also be equipped with the corresponding inspection technology to check the preform side walls for greater contamination (black specks) and sort out inadequate preforms accordingly. The inspection technology is only to be seen as an additional safeguard, as the material quality is already to be ensured during the manufacture of the granulated material and preforms.

10. Coating as a means of balancing out poor rPET qualities?

Doubts are justified as to whether additional coating of the bottles can ensure product quality in the case of poor packaging material.

In order to separate bottled beverages from possibly poor packaging material with the aid of a coating, the following requirements would have to be met:

- The coating covers the entire surface and can also withstand stresses.
- It must be possible to reject bottles with an inadequate coating or no coating at all from the process.

To meet both requirements, each individual bottle must be checked to ensure it has an intact coating and to determine the quality of the coating – without damaging it. However, the inspection technology to do so does not yet exist.

Those manufacturers who still wish to compensate for poorer recycled material qualities with a coating must take two things into consideration: Firstly, the investment and operating costs of a coating system and secondly the residual risk that comes with the lack of inspection options. It is also important to check how and whether the use of coating technology is permissible and sufficient under the locally applicable statutory requirements for recycled material in food grade application.

On the other hand, there is the option of relying on high quality food grade approved rPET from the start.

In light of today’s knowledge, it would seem that it is not possible to do without it, even if a coating is applied.

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11. rPET in aseptic applications

Recycled PET is also suitable for aseptic applications. The quantity of recycled PET that can be used essentially depends on three factors:

- The quality of the recycled material
- The process window of the aseptic application
- The level of the accepted, material induced rejection rate, which can also vary depending on the line configuration and production time

The rejection rate is sometimes increased due to unavoidable black specks and inhomogeneous areas. Due to the limited possibility for manual operator intervention, this can create a greater challenge in aseptic systems than in conventional ones.

12. rPET in hotfill applications

Recycled PET can also be used for hotfill applications. The possible quantity essentially depends on two factors:

a) **Quality and copolymer content of the rPET**
For heatset applications, Krones specifies an IV value of 0.78 to 0.84 dl/g and a copolymer content of less than 2 percent. The latter probably poses the greatest challenge for the use of rPET in the heatset procedure. For all of the other applications on the market are run with a higher copolymer content. However, if the recycling material is made of monofractional hotfill bottles, this percentage can also be increased considerably in heatset applications.

b) **Process window of hotfill applications**
Particularly when it comes to hotfill applications, there are some applications on the market which are already at the limits of what is technically possible and thus cannot withstand any additional process variations that may arise through the rPET percentage included.

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13. Conclusion and prospects

Applications with rPET are already being run on Krones production lines for many years now. The earliest reference projects were realised in 2003. Back then, the proportion of rPET included was already 30 percent, making it a good twenty years ahead of its time. Nowadays, the use of rPET is relatively widespread and, in the most cases, was implemented by our customers independently.

Thanks to the recycling technology available today, including that from Krones, we have tested packaging comprising up to 100 percent post-consumer recyclate and also put it into practice. The norm is between 20 and 60 percent. However, we know that some of our customers use higher percentages and that the trend is heading clearly in this direction.

We can therefore only welcome the fact that rPET has been gaining considerable momentum for some time now. For high-quality packaging materials such as PET still remain a valuable resource after their initial use. Keeping them in a closed loop makes sense, not only from an ecological but also from an economic viewpoint.

Regardless of whether with technology or knowledge: We are only too pleased to support and give advice to companies on how to use the benefits of recycling management to their advantage – while simultaneously making a valuable contribution to protecting the climate and preserving resources. An overview of our solutions and services regarding future-oriented plastic packaging can be found by visiting the “Plastics and sustainability” section under krones.com.

13. Conclusion and prospects

If you have any questions on this issue, please feel free to contact:

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