QUALITY ASSESSMENT OF PET BOTTLES PRODUCED THROUGH BOTTLE-TO-BOTTLE RECYCLING

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ABSTRACT

Different mechanical and thermal properties make Polyethene Terephthalic (PET) the most used plastic to produce water and carbonated beverage bottles. Bottles produced in the European Union (EU) contain, on average, only 17% of recycled PET (rPET) and this percentage must be raised to 30% by the year 2030 according to Directive (EU) 2019/904. A Deposit Return System (DRS) for PET bottles was implemented at the University of Aveiro, Portugal (UA), where students and staff are reimbursed for each PET beverage bottle returned, creating a flow of post-consumption plastic that is low in contamination and suitable for food-grade applications. This study conducts a comparative analysis of the quality between virgin PET bottles (0% rPET) and bottles comprising 50% rPET, manufactured using food-grade feedstock obtained from UA's DRS. This paper also presents a comprehensive methodology for assessing the quality of PET packaging with rPET and for further evaluation of the impact of successive recycling cycles on packaging quality at the chemical, structural and thermal levels, according to specific regulations for plastic packages in contact with food.

Keywords: Recycled PET (rPET); PET bottle; Bottle-to-bottle recycling; Post-consumer recycling (PCR).

INTRODUCTION

Polyethene Terephthalic (PET) is the most used plastic to produce water and carbonated beverage bottles due to its mechanical and thermal properties. These include high tensile strength, low susceptibility to breakage, clarity, lightweight and effective barrier properties against moisture and oxygen [1], [2]. Despite the growing rate of PET recycling [3], only a small percentage of it is used to produce new bottles. Even though beverage bottles account for over 60% of PET packaging and about 50% are recycled, the new bottles available on the EU market, on average, contain just 17% rPET [4]. Directive 2019/904 defines the integration of at least 30% of recycled plastic in the production of new bottles from 2030. The increase in the supply of food-grade rPET is crucial to produce new beverage bottles, as the European Safety Authority (EFSA) has stipulated that bottle feedstock must not contain more than 5% non-food PET plastic [5]. To achieve these targets and enhance the availability of food-grade rPET, one of the proposed measures in the Circular Economy Action Plan is the implementation of Deposit Return Systems (DRS) for PET bottles [6]. In 2020, REAP - Recycling and Reimbursement of Aluminum and PET Packaging project, was implemented at the University of Aveiro (UA), Portugal. This project enables students and staff at UA to receive a reimbursement for each PET beverage bottle returned, thereby creating a flow of post-consumption plastic that is low in contamination and suitable for food-grade applications such as the production of new bottles. Plastic packages in contact with food are subject to specific regulations (Commission Regulation (EU) Nº 10/2011) that also must be complied with when the incorporation of rPET. This paper aims to present methodologies required to evaluate the chemical, structural, and thermal characteristics of new bottles manufactured with rPET, also important to assess the impact on bottle quality after undergoing multiple cycles of recycling. The article provides a comparison between the quality of virgin PET bottles (0% rPET) and the quality of bottles containing 50% rPET, produced using food-grade feedstock obtained from UA's DRS and virgin PET for the others 50%.

MATERIALS AND METHODS

Materials

The bottles with 100% virgin PET and 50% virgin PET with 50% rPET were manufactured in the School of Design, Management and Production Technologies, University of Aveiro. The rPET component is derived from a mechanical recycling process, wherein the feedstock was obtained through the existing reverse vending machines at UA campi. All rPET used in production is originated from beverage bottles, and underwent separate collection, ensuring a minimal level of contamination.

Global and Specific Migration Analysis

Through global migration tests, the total mass of substances released by the plastic material, when in contact with the foodstuff or its simulant, is determined. Specific migration makes it possible to assess the transfer of specific substances from plastic to food. The global migration and specific migrations of terephthalic acid and bisphenol A were evaluated. For migration tests the bottles were prepared according to “Materials and articles in contact with foodstuffs - Plastics – European Standards“ and Commission Regulation (EU) Nº 10/2011 on plastic materials and articles intended to come into contact with food [7]. The bottles were filled with different simulators and were subjected to a contact time of 10 days at 50ºC, settings that cover the common storage conditions. The tests were carried out with two simulators, simulator B (acetic acid at 3% w/v) and simulator C (ethanol at 20% v/v) that replace the use of clear non-alcoholic beverages or alcoholic beverages with an alcohol content equal to or less than 6% v/v [7]. The use of the two simulators allows to represent this category of beverages regardless of their pH. Regarding the specific migration, only two modifications were implemented in relation to the European Standards. These changes include the utilization of a different HPLC column, specifically the Teknokrama BRISA LC2 C18 5 5μm 15*0.46, and the injection volume of 10 μL.

Structural and Thermal analysis

Fourier transform infrared spectroscopy (FTIR) - The infrared spectrum was obtained in a IRAffinity-1, Shimadzu Corporation, Japan in attenuated total reflectance (ATR) within the 2000–700 cm^{-1} range, with a resolution of 4 cm^{-1} and 32 scans. Three replicates of each incorporation fraction were performed.

The thermogravimetric analysis (TGA) was performed on a NIEXTA STA300. The samples were heated from the ambient temperature to 550 °C at a heating rate of 10 °C/min under a nitrogen atmosphere. Two replicates of each incorporation fraction were performed.

RESULTS AND DISCUSSION

Migration analysis

The global migration results were subjected to a statistical analysis using an analysis of variance (ANOVA). This analysis helps determine whether there are significant differences between averages, in this case between the samples and the control group for the two types of bottles produced and analyzed with the two different simulators. When the ρ-value is less than 0.05, we can conclude that a significant difference exists, whereas a ρ-value larger than 0.05 does not allow us to draw a conclusion. In the case of the 0% rPET bottles and 50% rPET bottles with simulator B, the ρ-value is higher than 0.05, indicating no significant differences. However, for the 50% rPET bottles with simulator C, there are significant differences, but the overall migration values remain well below the legislatively mandated limit (10 mg/dm2). Thus, it is possible to determine that there is no significant migration in the analyzed bottles, even when they are produced with a 50% rPET content.

Table 16. Variance analysis (ANOVA) results of global migration.

rPET fraction	Simulator	δf	ρ-value
0% rPET	B	4	0,133
	C	4	0,969
50% rPET	B	4	0,615
	C	4	0,020

For specific migration, ion chromatography for terephthalate did not detect terephthalic acid or bisphenol A in any incorporation fraction for any of the simulants.

Structural and thermal analysis

No differences were detected in the PET structure, as shown in Fig.1. The structural analysis through FTIR of PET bottles with the incorporation of 50%rPET in relation to the structure of the bottles with 0%rPET reveals no changes.

Regarding the thermal analysis, two replicates were conducted for each incorporation fraction (see a result example in Fig.2). It was observed that the 50% rPET fraction left a higher residue (13.01% and 14.48%) compared to the 0% rPET fraction (10.04% and 12.35%). This residue increase (about 1.2%) could be attributed to the additives typically employed in the production of commercial bottles which were used in the incorporation of 50% rPET bottles in the recycling process.

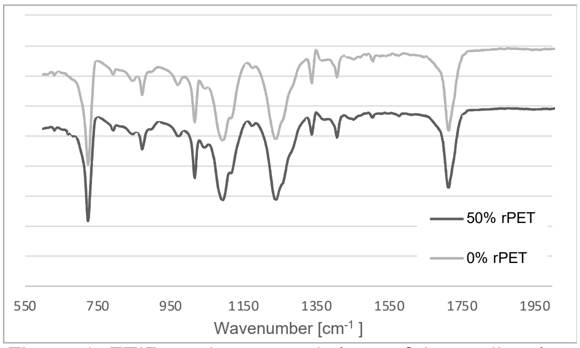

Figure 1. FTIR analyses result (one of the replicas).

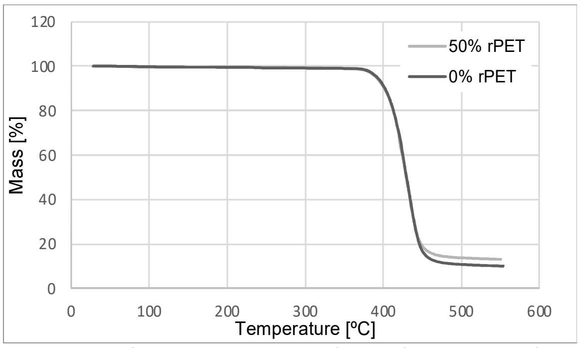

Figure 2. TGA analyses result (one of the replicas).

CONCLUSION

No significant changes were detected in the quality of the bottles produced with 50% rPET in the first recycling cycle. These results demonstrate the effectiveness of recycling when waste contamination is minimal and underscore the significance of selective collection and bottle-to-bottle recycling. The utilization of a DRS for bottle collection enables the acquisition of cleaner residues that are ready to integrate the production of new bottles with food-grade quality.

For future work, it is important to evaluate different levels of incorporation of rPET in the production of new bottles and to evaluate the effects of successive recycling cycles according to European regulations for plastic packages in contact with food.

This article compiles the essential methodology for quality assessment of PET packaging with rPET for further evaluation of the effect of consecutive recycling cycles on packaging quality at the chemical, structural and thermal levels.

References

[1] M. Chanda, *Plastics Technology Handbook*, Fifth Edition. CRC Press, 2018.

[2] F. Welle, “Twenty years of PET bottle to bottle recycling - An overview,” *Resources, Conservation and Recycling*, vol. 55, no. 11. pp. 865–875, Sep. 2011. doi: 10.1016/j.resconrec.2011.04.009.

[3] Eunomia, “Pet Market In Europe State Of Play 2022 Production, Collection And Recycling,” 2022.

[4] A. Grant, V. Lahme, T. Connock, and L. Lugal, “How Circular is PET?,” Feb. 2022.

[5] M. T. Brouwer, F. Alvarado Chacon, and E. U. van Velzen, “Effect of recycled content and rPET quality on the properties of PET bottles, part III: Modelling of repetitive recycling,” *Packaging Technology and Science*, vol. 33, no. 9, pp. 373–383, 2020, doi: https://doi.org/10.1002/pts.2489.

[6] European Comission, “European Green Deal: Putting an end to wasteful packaging, boosting reuse and recycling,” Nov. 30, 2022.

[7] Commission Regulation (EU) Nº 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food.