Removal of insoluble additives from polystyrene by applying centrifugation in solvent-based recycling

E. Carrieri[1], M. Stefanidou[1], A. Grass[1], M. Vanwynsberghe[1], S. De meester[1]

[1]Laboratory for Circular Process Engineering (LCPE), Department of Green Chemistry and Technology, Ghent University, Graaf Karel de Goedelaan 46, 8500 Kortrijk,
Belgium

Keywords: plastic recycling, additive, centrifugation, polystyrene, DoE.
Presenting author email: elisabetta.carrieri@ugent.be

Plastics have become indispensable materials in modern industrialized societies. In 2023, over 400 Mt of plastics were produced globally, of which 5.2% was polystyrene (PS) (Plastics Europe, 2024). PS exhibits versatile and customizable properties, making it suitable for a wide range of applications across multiple sectors, including packaging (e.g., yogurt cups, fish boxes), electrical and electronics (e.g., refrigerators), building and construction (e.g., insulation foams), automotive (e.g., bumpers), as well as various other uses such as toys, discs, and cosmetic containers. PS can be used as such (general-purpose polystyrene - GPPS) or added with impact modifiers, as in the case of high-impact polystyrene (HIPS), where grafted polybutadiene (PB) rubber particles are added to increase the impact resistance properties of PS (Acuña et al., 2009). When collected and sorted, rigid PS-based waste streams contain both HIPS and GPPS, thus when they are mechanically recycled, a thermo-oxidative degradation of the rubber particles is likely to occur (Israeli et al., 1994), consequently lowering the quality of the recyclate. Hence, the removal of these PB-based particles would enhance the recycling of PS-based waste. Besides rubber particles, also additives, typically added to the polymeric matrix during the manufacturing process, can undermine recycling operations. An example are pigmented plastics that when mechanically recycled tend to end up in dark-coloured material that have a much lower market value (Ügdüler et al., 2020), as well as creating pigment migration that affects the performance abilities of plastics (Schyns and Shaver, 2021).

Solvent-based recycling, or dissolution recycling, offers a promising alternative to traditional mechanical and chemical recycling methods. Unlike thermal-based methods that break down polymer chains, such as thermal depolymerization or pyrolysis, which require energy-intensive purification of the obtained mixtures, solvent-based recycling avoids these high energy demand, while still enabling the effective removal of contaminants and additives. With this method the polymer is first dissolved in a suitable solvent, then the obtained polymer solution, containing also additives and contaminants originally present in the plastic, undergoes a solid-liquid separation step to remove the insoluble matter. Afterwards the polymer is recovered through precipitation, typically achieved by means of antisolvent addition. Finally, the precipitated polymer is separated from the liquid solution via filtration.

This study investigates the use of centrifugation as a separation technique for the removal of insoluble additives from PS solutions within a solvent-based recycling process. In order to systematically evaluate the effect of key physicochemical and operational parameters on separation efficiency, A Design of Experiments (DoE) approach was employed. Polymer solution viscosity and density, polymer concentration, density and size of the additives, rotational speed, and residence time were included in the DoE. Five different additives and three different solvents were selected: TiO_2 and carbon black, as white and black pigments (the most used ones), a yellow pigment (Cr/Sb/Ti oxide), one of the most used fillers, $CaCO_3$, and rubber particles of HIPS; limonene, o-xylene and geranyl acetate. The centrifugation tests were performed at room temperature after the dissolution of the additive-compounded PS (one additive at a time) in the selected solvent. Turbidity reduction (respect to the original solution) of the supernatant was chosen as parameters to evaluate separation efficiency. A statistical analysis of the experimental results was then performed based on a linear regression model, that enabled the identification of significant factors and interaction effects, and provided optimized operating windows.

To bridge laboratory insights with industrial application, scale-up calculations were performed for industrial disk-stack and decanter centrifuges, incorporating sedimentation theory, Sigma factor correlations, and equipment-specific geometries. Predicted throughputs and separation efficiencies under industrially relevant conditions were compared with experimental data to assess process robustness and scalability.

To summarize, this study assesses centrifugation as separation technique to remove different types of additives from polystyrene solutions within solvent-based recycling, employing a statistical tool (DoE) to evaluate and optimize the different parameters involved in the process. Furthermore, laboratory results were combined with scale-up calculations and considerations to assess industrial feasibility and guidance for implementation of centrifugation in large-scale recycling processes.

Acknowledgments

We gratefully acknowledge the financial support of Flanders Innovation & Entrepreneurship (VLAIO) through the Catalisti Moonshot project Renovate 2 (HBC.2022.0536).

References

Acuña, P., Morales, G., de León, R.D., 2009. Synthesis and characterization of high-impact polystyrene using a multifunctional cyclic peroxide as the initiator. Journal of Applied Polymer Science 114 (5), 3198-3210. https://doi.org/10.1002/app.30932

Israeli, Y., Lacoste, J., Lemaire, J., Singh, R. P., Sivaram, S., 1994. Photo- and thermoinitiated oxidation of high impact polystyrene. Characterization by FT-IR spectroscopy. Polymer Chemistry 32 (3), 485-493. https://doi.org/10.1002/pola.1994.080320310

Plastics Europe, 2024. Plastics – The fast Facts.

Schyns, Z.O., Shaver, M.P., 2021. Mechanical recycling of packaging plastics: A review. Macromolecular Rapid Communications 42 (3), 2000415. https://doi.org/10.1002/marc.202000415

Ügdüler, S., Van Geem, K.M., Roosen, M., Delbeke, E.I., De Meester, S., 2020. Challenges and opportunities of solvent-based additive extraction methods for plastic recycling. Waste Management 104, 148-182. https://doi.org/10.1016/j.wasman.2020.01.003