

Towards faster polymer dissolution for dissolution recycling: a case-study for polystyrene foams

Rita Kol^{a,b}, Ruben Denolf^a, Gwendoline Bernaert^a, Dave Manhaeghe^a, Ezra Bar-Ziv^c, George. W. Huber^d, Norbert Niessner^e, Michiel Verswyvel^f, Angeliki Lemonidou^g, Dimitris S. Achilias^b, Steven De Meester^a

^aLaboratory for Circular Process Engineering, Department of Green Chemistry and Technology, Ghent University, Sint-Martens-Latemlaan 2B, 8500 Kortrijk, Belgium

^bLaboratory of Polymer Chemistry and Technology, Department of Chemistry, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

^cDepartment of Mechanical Engineering, Michigan Technological University, Houghton, MI, 49931, United States of America

^dDepartment of Chemical and Biological Engineering, University of Wisconsin—Madison, Madison, Wisconsin 53706, United States

^eINEOS Styrolution GmbH, Mainzer Landstraße 50, 60325 Frankfurt am Main, Germany

^fINEOS Styrolution Belgium N.V., Scheldelaan 600, 2040 Antwerpen, Belgium

^gLaboratory of Petrochemical Technology, Department of Chemical Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

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Presenting author email: rita.duarte@ugent.be

1. Introduction

There is a urgent need to close the loop for plastics. Dissolution recycling (also known as solvent-based recycling) has the advantage of cleaning the polymer matrix whilst avoiding the energy cost for depolymerization (Kol, 2021). The principle of dissolution recycling is to dissolve the polymer in a suitable solvent, remove insoluble particles with a solid-liquid separation process, precipitate the polymer from solution by adding an antisolvent, and recover the precipitated polymer with a solid-liquid separation process and perform the necessary drying step (Kol, 2021). In industry it is especially important to have a fast process, without waiting hours before the polymer is completely dissolved. The dissolution of polymers is a complex process and involves several mass transfer processes. These include the diffusion of the solvent into the polymer, the swelling of the polymer and the disentanglement of the polymer from the swollen gelly layer to the bulk solution (Miller-Chou, 2003). In this work we have studied the influence of solvent properties, temperature, particle size, stirring speed, impeller type and reactor design on the dissolution rate of polystyrene (PS).

2. Materials & Methods

A total of 33 solvents were tested for a first dissolution screening of polystyrene (Polystyrene “GPPS”: Styrolution® PS 168 N). The waste sample used in this study was PS coming from foamed fish boxes, which were collected from a sorting facility as a big non-washed compressed block. Prior to dissolution, the waste PS was washed, dried, shredded and finally sieved to obtain the desired particle size distribution. The dissolution kinetics was performed with cyclohexene (ChemLab, >99%), in a lab-scale reactor (250 mL round-bottom flask) and in a baffled reactor (500 mL thermostatic reaction vessel) which proportions that follow a typical standard agitation system (Figure 1). The dissolution kinetics was studied under different conditions of reactor type (lab-scale and baffled reactor), temperature (25, 50 and 75 °C), particle size ($1.0 < d_p < 1.18$ mm, $1.18 < d_p < 2.0$ mm, $2.0 < d_p < 2.36$ mm), impeller speed (750, 875, 1000 rpm) and impeller type (Rushton turbine, propeller-type).

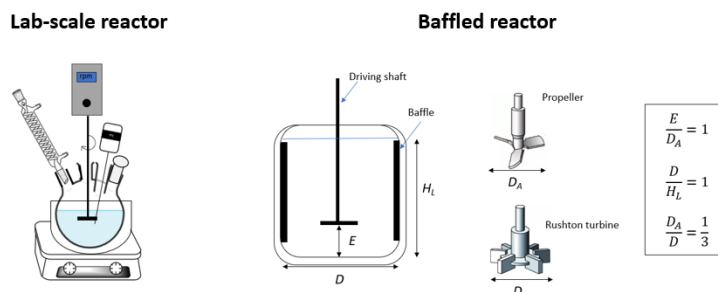


Figure 1. Schematic picture of lab-scale (left) and baffled reactor (right).

3. Results & Discussion

The results of the first dissolution screening show that cyclohexene, 2-pentanone, ethylbenzene and methyl ethyl ketone are the solvents that dissolve the highest amount of polystyrene in the studied time frame of 30 minutes. This analysis is followed by the development of a multiple regression model which shows that within

several solvent properties, the viscosity of the solvent is the major contributor to the dissolution time, followed by the dispersion, polar and hydrogen bonding (solubility) parameters.

The dissolution kinetics of polystyrene in cyclohexene in a lab-scale reactor shows that a higher particle size and lower temperature result in a lower dissolution rate (Figure 2a). At 50 °C for the particle size distribution of $1.18 < d_p < 2.0$ mm, full dissolution was obtained at approximately 60 minutes. At the same conditions of particle size and temperature, the dissolution in a baffled reactor took approximately 7 minutes (Figure 2b). Furthermore, the dissolution in a baffled reactor with a Rushton turbine showed to be independent on the stirring speed, which was not the case for the propeller.

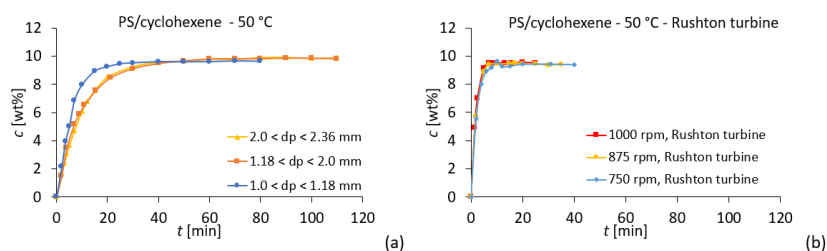


Figure 2. Dissolution results of PS/cyclohexene at 50 °C in (a) lab-scale reactor at different particle size fractions (250 rpm), (b) in a baffled reactor at different stirring speed for the particle size fraction of $1.18 < d_p < 2.0$ mm.

The application of a first-order kinetic model confirms that the dissolution in a baffled reactor is at least fivefold faster than in a lab-scale reactor. This is related with the erosion of the gel layer due to the stirring and turbulence. Finally, the dissolution kinetics of a real waste sample reveals that in optimized conditions full dissolution occurs in 5 minutes, which is quite similar to pure PS (Figure 3a). This result also reveals that despite the unexpected yellowish color of the waste PS solution (Figure 3b), the dissolution kinetics were not affected by the presence of these contaminants and/or additives.

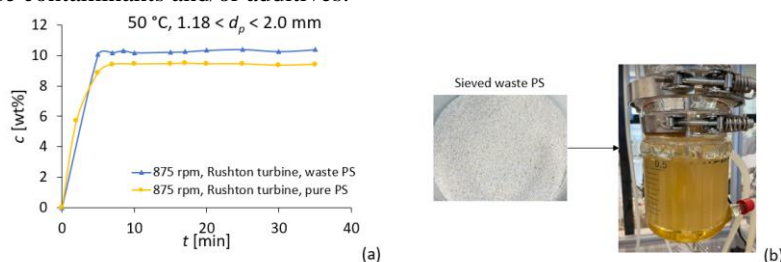


Figure 3. (a) Dissolution results for waste PS compared to pure PS and (b) dissolved waste in baffled reactor.

4. Conclusion

This work shows that within several solvent properties, the viscosity of the solvent is the major contributor to the dissolution time of the polymer, followed by the dispersion, polar and hydrogen bonding (solubility) parameters. Furthermore, this work shows the importance of proper reactor design towards a fast dissolution of polystyrene, which enables a step forward towards the industrial implementation of dissolution recycling for polystyrene.

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