Understanding the complexity of deinking plastic waste: An assessment of the efficiency of different treatments to remove ink resins from printed plastic film

S. Ügdüler[1], S. De Meester[1]

[1]Laboratory for Circular Process Engineering (LCPE), Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Kortrijk, 8500, Belgium
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Presenting author email: sibel.ugduler@ugent.be

Introduction

One of the components impeding the closed-loop recycling of flexible packaging is the use of printing inks. Typically, plastic packaging is extensively printed using various printing technologies, serving essential functions such as conveying information about composition, allergens, and nutritional details. Additionally, printing enhances the visual appeal of packaging for marketing purposes. Despite the indispensability of inks in plastic packaging, they pose a notable challenge as a major source of contamination in the plastic recycling process. As all printed plastic films are generally collected and processed together, low-quality dark colored recyclates are obtained, resulting in downcycled products.(Gabriel and Maulana, 2018) Moreover, in the course of reprocessing, residual ink may undergo decomposition, giving rise to the generation of gases. This not only leads to the development of an unpleasant rancid odor but also contributes to a deterioration in the physical properties of the raw material.(Izdebska and Thomas, 2016) Hence, the price of recycled films containing inks is considerably lower than that of transparent films.(Horodytska et al., 2018) In an effort to address these challenges and secure high-quality recyclates, there is a growing interest in the development and adoption of deinking technologies. Despite numerous investigations into media for removing resin from plastic film waste, a comprehensive study is notably lacking, one that specifically endeavors to comprehend the efficacy of these media in the deinking process for various types of inks. Given the diverse range of chemically distinct polymer resins utilized in the production of printing inks, it is questionable whether all treatments could remove all resins and how effective they could be. Although each commercial deinking process claims to have superior deinking performance, drawing precise comparisons regarding the effectiveness of various deinking processes against specific ink types is challenging. Therefore, the objective of this study was to gain a systematic understanding of the effectiveness of different media in different types of polymer resins. This is achieved by the investigation of liquefaction and maximum solubility of 14 chemically different polymer resins which are typically used in printing inks for plastic films in seven different media used in plastic pretreatment, such as acetone, ethyl acetate, NaOH solution, CTAB solution, formic acid, sulfuric acid and DMCHA. The deinking efficiency tests on pure resins are also confirmed by deinking four printed plastic films containing different classes of polymer resins. A basic cost and environmental impact analysis is given to evaluate scale-up potential of the deinking medium.

Materials and Methods

The maximum solubility of each polymer resin in seven different liquid media (i.e., acetone, ethyl acetate, NaOH solution, formic acid, sulfuric acid, CTAB solution, and DMCHA) was determined through UV-VIS and thermogravimetric analysis with Fourier transform infrared spectroscopy (TGA-FTIR) by making calibration curves. Once the maximum solubility of each polymer in each medium was defined, kinetic tests were performed at RT to investigate the liquefaction rate of the polymer resins. The collected aliquots were analyzed using UV-VIS or TGA-FTIR for the quantification of the dissolved polymer resin during the kinetic tests.

In order to establish a correlation between the liquefaction rate of the polymer resin and the deinking rate of plastic film printed with that particular polymer resin, kinetic tests were conducted on the printed plastic films. First, each printed plastic film was cut to a 2.5 cm × 3 cm, then these cut samples were brought into contact with each liquid medium at RT by stirring via a rotary shaker. The surface of the collected samples were then scanned to calculate the remaining ink density on the plastic surface to follow the deinking process of the printed plastic film in each medium. To determine the deinking percentage of printed plastic films in different media, a reflection densitometry approach was used to measure the amount of residual pigment by means of the intensity of the reflected light.

Results and Discussions

The maximum solubility of 14 chemically different polymer resins was determined at RT in seven different media typically used in plastic pretreatment (i.e., acetone, ethyl acetate, NaOH solution, CTAB solution, formic acid, sulfuric acid, and DMCHA) (Figure 1). The findings indicate that acid-based media exhibited greater efficiency in liquefying a broader spectrum of polymer resins. Specifically, sulfuric acid showed the highest solubility capacity for different classes of polymer resins (> 0.1 g/mL on average). Compared with sulfuric acid, formic acid does not have oxidation capability; thus, it resulted in a lower solubility capacity, especially for polyurethane (PU)

based polymer resins. Among the tested organic solvents (i.e., acetone, ethyl acetate, and DMCHA), acetone and ethyl acetate were more effective than DMCHA, especially for the solubilization of acrylic-related polymer resins. The apolar nature of DMCHA resulted in relatively low solubility (< 0.0024 g/mL) for all the tested polymer resins which have a relatively polar chemical bond. Regarding the water-based media (i.e., NaOH and CTAB solutions), the NaOH solution resulted in a low solubility of polymer resins (< 0.09 g/mL). The addition of the surfactant CTAB to the basic medium increased the solubility capacity, especially for the cellulosics and acrylic-related polymer resins.

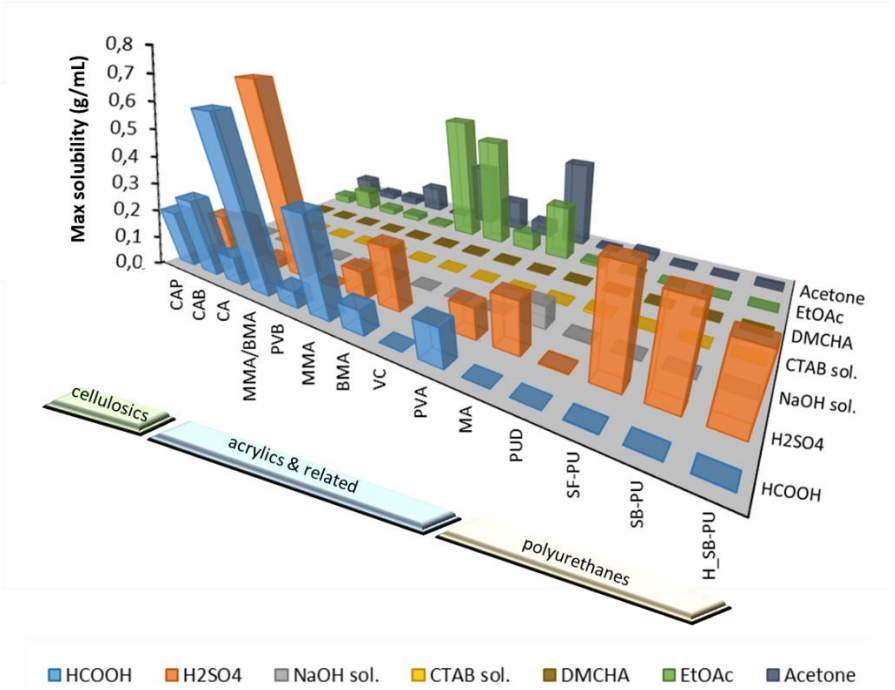

Figure 1. Maximum solubility of different polymer resins in seven different media at RT.

Once the maximum solubility of each polymer resin in each medium was set, the liquefaction processes of these 14 polymer resins were investigated in each medium at RT. The diverse physiochemical characteristics of polymer resins manifested distinct liquefaction processes. Among the tested media, acid-based media (i.e., sulfuric acid and formic acid) resulted in the highest liquefaction for most of the polymer resins, reaching more than 80% liquefaction at a 30-min interval. In the tested organic solvents (e.g., acetone, ethyl acetate, and DMCHA), cellulosic and acrylic polymer resins reached more than 50% liquefaction after 30 min of interaction time. In the alkaline medium, most of the tested polymer resins showed the lowest liquefaction process.

The liquefaction data obtained on pure polymer resins were confirmed by deinking plastic films printed with inks containing nitrocellulose (NC) polymer resin, acrylate polymer resin, polyvinyl butyral (PVB) polymer resin and PU polymer resin. The outcomes of the liquefaction tests conducted with pure polymer resins align with the observed deinking efficiency results. For example, the highest deinking efficiency was also observed in the acid-based media, resulting in more than 60% deinking efficiency within 5 min of interaction. Notably, formic acid exhibited a low deinking efficiency when applied to the printed plastic film containing acrylate polymer resin. Among the tested organic solvents, acetone showed high deinking efficiency for plastic films containing NC and PU polymer resins, reaching more than 80% deinking efficiency in 10 min of interaction. Basic media yielded low deinking kinetics for the examined printed plastic films. The presence of CTAB substantially enhanced the deinking efficiency, especially for plastic films containing NC, acrylate, and PVB polymer resins.

In addition to assessing the efficacy of the liquid medium, certain considerations related to upscaling were taken into account. Among the different media, the lowest amount of sulfuric acid (0.002–0.364 L) was sufficient to deink 1 m² of printed plastic film, followed by acetone (0.007 L–1.849 L). However, the technical feasibility of the medium, such as flashpoint, handling, and corrosiveness, are also crucial points to be considered for scaling up of the deinking process. The initial cost evaluation for deinking approximately 100 kg of plastic film revealed that both the cost of the chemical and its necessary volume for achieving effective deinking play pivotal roles in determining the overall cost of the deinking process. In terms of the environmental impact associated with chemical production, ethyl acetate emerges with the highest human toxicity, while DMCHA demonstrates the most significant impact on CO_2 emissions throughout their life cycle. These results are only indicative, and their applicability may vary based on the specific conditions of the deinking process and the types of polymer resins present in the plastic waste feedstock.(Ügdüler et al., 2023)

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