A Sustainable Approach to Recycling Multi-Layer Aseptic Packaging

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Abstract

Aseptic cartons, composed of layered low-density polyethylene (LDPE), paper, and aluminum, pose significant recycling challenges due to their complex composite structure. This study develops an optimized chemical recycling process for these materials, focusing on the selective dissolution of LDPE using a solvent blend of gasoline, xylene, and toluene in a 50:25:25 (v/v) ratio. The Plackett-Burman experimental design identified key parameters affecting LDPE dissolution, including solid-to-liquid ratio, double-layer seams, temperature, and time. Complete LDPE dissolution was achieved at 120°C for 30 minutes, with 100% LDPE recovery and 90% solvent recovery. The elimination of the hydropulping step improved LDPE dissolution efficiency, while an eddy current separator (ECS) was proposed for effective aluminum-paper separation. This closed-loop recycling method supports sustainable waste management and aligns with circular economy principles by enabling the reuse of all components. Further studies on scalability, economic feasibility, and environmental impacts are needed for industrial implementation.

Keywords: Tetra Pak; Aseptic cartons; Multi-layer composites; Chemical recycling; Eddy current separation

Introduction

Aseptic packaging, widely used in food and pharmaceutical industries, extends product shelf life by preventing oxygen, light, and moisture ingress. Typically, these cartons (e.g., Tetra Pak) consist of approximately 70% paper, 25% LDPE, and 5% aluminum, laminated into a composite structure. While these materials are individually recyclable, their integrated matrix complicates separation, posing challenges for waste management. Traditional recycling methods, such as hydropulping, focus on paper recovery but often yield low-purity aluminum-polyethylene (Al-PE) residues, reducing overall efficiency [1]. The circular economy emphasizes minimizing waste and reusing materials, making the development of efficient recycling methods for aseptic cartons critical. This study proposes a novel closed-loop recycling process that avoids hydropulping, optimizes LDPE dissolution, and employs eddy current separation for aluminum and paper, contributing to sustainable waste management and resource recovery.

Methodology

Aseptic cartons from brands such as Tetra Pak, SIG, Alvand Pack, and Sun Pack were collected, cleaned, and cut into 1.5 cm × 1.5 cm pieces. The LDPE dissolution process used a solvent mixture of gasoline (38–204°C boiling range), xylene (99%, 140°C boiling point), and toluene (99%, 110°C boiling point). The Plackett-Burman design (12 runs) was applied using Minitab 21 to screen influential parameters, including solid-to-liquid ratio (S/L), piece size, temperature, time, stirring speed, and double-layer seams [2]. Dissolution experiments were conducted in a 50 mL Erlenmeyer flask at 90–120°C for 15–30 minutes with 200 rpm stirring. Post-dissolution, solids were filtered, washed, and dried, and LDPE dissolution was calculated via weight loss (Equations 1 and 2). The solvent-LDPE solution was distilled at 210°C to recover LDPE and solvents. Fourier Transform Infrared (FTIR) spectroscopy (Bruker Tensor 27, 4000–600 cm^{-1}) verified LDPE purity. Aluminum and paper separation was tested using an eddy current separator (ECS) to replace hydropulping.

Results and Discussion

The optimal solvent ratio of gasoline:xylene:toluene (50:25:25 v/v) achieved complete LDPE dissolution at 120°C for 30 minutes across all tested brands, with Tetra Pak reaching 98% dissolution under standard conditions (90°C, 15 minutes). Increasing temperature to 120°C and time to 30 minutes ensured 100% LDPE dissolution, even for brands like Alvand Pack, which initially showed 81% dissolution. The Plackett-Burman analysis identified solid-to-liquid ratio and double-layer seams as the most influential factors, with higher S/L ratios increasing solution viscosity and reducing solvent penetration, and double-layer seams decreasing LDPE-solvent contact. FTIR analysis confirmed the recovered LDPE's chemical integrity, matching reference spectra with characteristic peaks at 2915 cm^{-1} (C-H stretch) and 1463 cm^{-1} (C-H bend) (Figure 1). A slight green tint in the recovered LDPE, likely from gasoline pigments, did not affect purity. Recovery rates were 100% for LDPE and 90% for solvents, with losses attributed to transfer and evaporation. Traditional aluminum-paper separation methods (e.g., density-based) failed due to surface tension effects, but ECS effectively separated aluminum from paper, eliminating the need for hydropulping [3, 4]. This omission also avoided LDPE degradation, enhancing material quality. Compared to hydropulping-based methods (80–95% paper recovery, low-purity Al-PE), this process achieved higher recovery rates and purity, reducing water and energy use by approximately one-third.

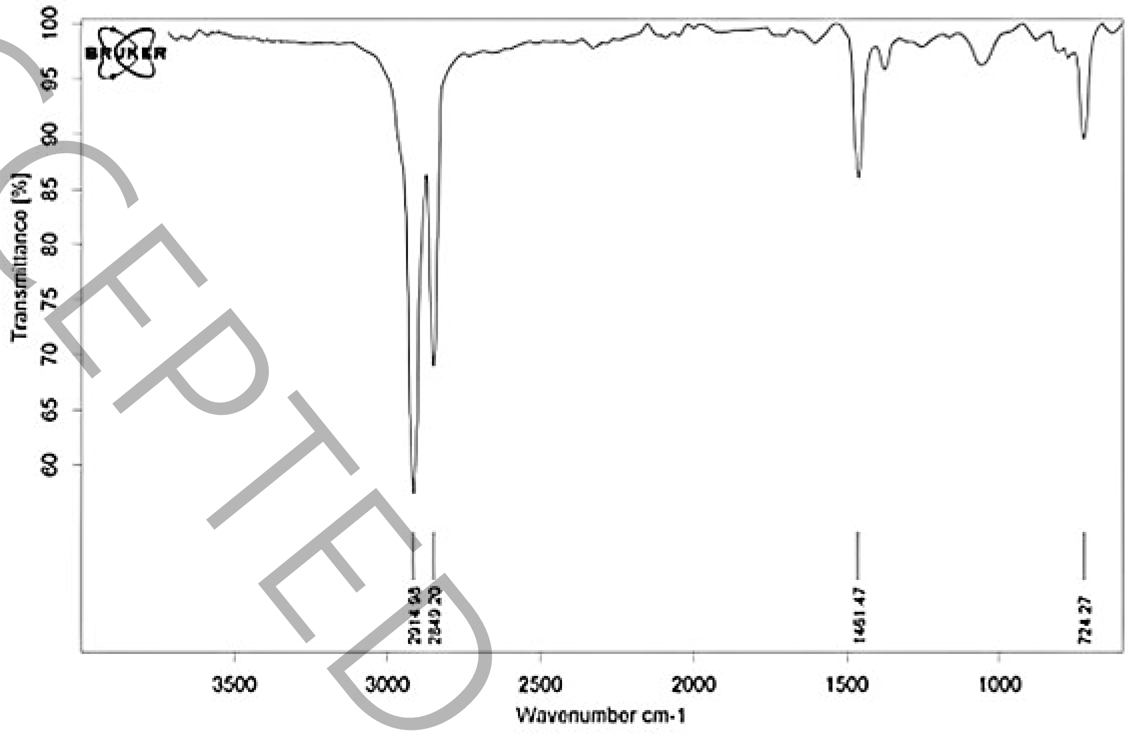

Figure 1. FTIR spectra of recovered LDPE.

Conclusion

This study presents an innovative closed-loop recycling process for aseptic cartons, achieving 100% LDPE recovery and 90% solvent recovery using an optimized gasoline:xylene:toluene (50:25:25) solvent blend. By eliminating hydropulping, the method preserves LDPE quality and reduces water and energy consumption. The use of ECS for aluminum-paper separation enhances efficiency over traditional methods. The process aligns with circular economy principles by enabling direct reuse of LDPE, paper, and aluminum. However, limitations include the lab-scale nature of the study, the use of volatile solvents, and the need for broader applicability testing. Future research should focus on industrial scalability, economic analysis, and safer solvent alternatives to minimize environmental impacts.

Reference

[1] I. Georgiopoulou, G.D. Pappa, S.N. Vouyiouka, K. Magoulas, Recycling of post-consumer multilayer Tetra Pak® packaging with the Selective Dissolution-Precipitation process, Resources, Conservation and Recycling, 165 (2021) 105268-105268.

[2] G.G. Şahin, M. Karaboyacı, Process and machinery design for the recycling of tetra pak components, Journal of Cleaner Production, 323 (2021) 129186-129186.

[3] A. Cervantes-Reyes, A. Núñez-Pineda, C. Barrera-Díaz, V. Varela-Guerrero, G. Martínez-Barrera, E. Cuevas-Yañez, Solvent effect in the polyethylene recovery from multilayer postconsumer aseptic packaging, Waste Management, 38(1) (2015) 61-64.

[4] Y.R. Smith, J.R. Nagel, R.K. Rajamani, Eddy current separation for recovery of non-ferrous metallic particles: A comprehensive review, Minerals Engineering, 133 (2019) 149-159.