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Sustainability Assessment and Solvent Reusability in Alkaline Hydrolysis of Polyethylene Terephthalate (PET): A Green Chemical Recycling Approach

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ABSTRACT: *The global rise in polyethylene terephthalate (PET) consumption necessitates sustainable recycling pathways. This study investigates the environmental performance and solvent reusability in alkaline hydrolysis of PET using methanol and ethylene glycol. PET flakes were depolymerized with sodium hydroxide under controlled conditions, followed by neutralization with sulfuric acid. Fourier Transform Infrared (FTIR) spectroscopy characterized both solid and liquid fractions. Ethylene glycol retained structural stability, enabling reuse with minimal purification, whereas methanol showed degradation peaks, indicating reduced recyclability. The results demonstrate that solvent reusability directly enhances process sustainability, reduces waste, and supports circular economy models.*

KEYWORDS: PET; Alkaline hydrolysis; Solvent reusability; Ethylene glycol; Methanol; FTIR; Green chemistry.

1. Introduction

Polyethylene terephthalate (PET) is among the most widely used thermoplastic polymers, particularly in packaging, textiles, and beverage containers. Global PET production surpassed 80 million tonnes annually [1]. However, its persistence and low biodegradability contribute to severe environmental challenges [2].

Mechanical recycling of PET often leads to property degradation due to hydrolytic instability [3]. In contrast, chemical recycling—specifically alkaline hydrolysis—offers a method to recover valuable monomers such as terephthalic acid (TPA) and ethylene glycol (EG) [4].

Recent studies highlight the need to integrate sustainability and solvent reusability into chemical recycling frameworks [5,6]. Solvents like methanol and ethylene glycol act as DE polymerization media but also influence energy consumption, purity of recovered products, and potential for closed-loop reuse [7,8].

The solvent recovery phase represents a crucial stage in life-cycle environmental assessment (LCA) [9]. Degraded solvents increase both the energy footprint and hazardous waste load [10]. Conversely, reusable solvents align with circular economy principles, lowering emissions and reducing reliance on virgin materials [11–13]. This paper evaluates the environmental sustainability and reusability of methanol and ethylene glycol in PET alkaline hydrolysis, using experimental data validated through FTIR analysis.

2. Materials and Methods

2.1 Materials

Post-consumer PET bottles were cleaned, dried, and cut into flakes (6–8 mm × 3–5 mm). Analytical-grade sodium hydroxide (NaOH), methanol (CH_3OH), ethylene glycol ($C_2H_6O_2$), and sulfuric acid (H_2SO_4) were used [14].

Table 1. General properties of materials used in PET hydrolysis.

Material	Formula	Boiling Point (°C)	Density (g/cm³)	Solubility
PET	$(C_{10}H_8O_4)_n$	—	1.38	Insoluble in water
Ethylene glycol	$C_2H_6O_2$	197	1.11	Miscible
Methanol	CH_3OH	64.7	0.79	Miscible
Sodium hydroxide	NaOH	1388	2.13	Soluble

2.2 Experimental Setup

The experimental arrangement included a steel reactor, electric heater, thermometer, conical flasks, and FTIR spectrometer (*Figure 1*). PET flakes were reacted with NaOH dissolved in each solvent separately at elevated temperatures (90–250°C). After full melting, the mixture was cooled and neutralized with 34% H_2SO_4, precipitating TPA.

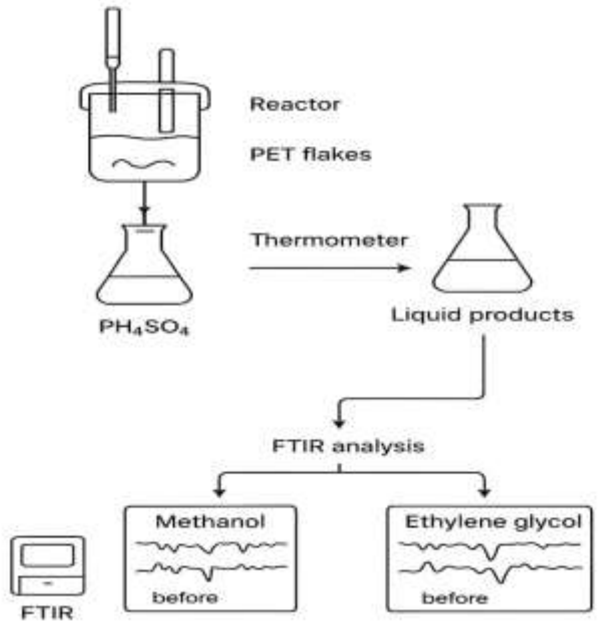

Figure 1. Experimental setup for alkaline hydrolysis of PET using methanol and ethylene glycol.

2.3 Solvent Recovery

The liquid phase obtained after filtration was analyzed via FTIR spectroscopy (4000–500 cm^{-1}). Solvent reusability was evaluated by comparing functional group retention and spectral similarity with pure reference solvents (*Figure 2*).

Figure 2. FTIR analysis workflow for solvent characterization.

3. Results and Discussion

3.1 FTIR Characterization of Solid Products

FTIR spectra of solid TPA products exhibited characteristic peaks at 3100–3000 cm^{-1} (C–H stretching), 1680–1690 cm^{-1} (C=O stretching), and a broad O–H band (2500–3300 cm^{-1}), confirming high-purity TPA formation.

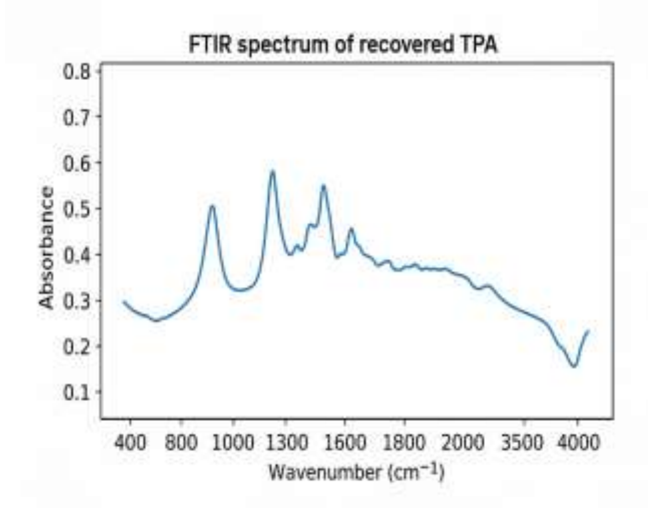

Figure 3. FTIR spectrum of terephthalic acid recovered from PET hydrolysis.

These findings align with Pereira et al. [16] and Amundarain et al. [17], confirming efficient depolymerization.

3.2 FTIR Characterization of Liquid Fractions

Ethylene glycol-derived liquids showed FTIR profiles almost identical to the pure solvent, retaining major absorption bands at 3200–3500 cm^{-1} (O–H stretching) and 1080–1110 cm^{-1} (C–O stretching) [18]. Methanol-derived liquids, however, displayed additional carbonyl peaks near 1720 cm^{-1}, suggesting oxidative degradation or ester formation

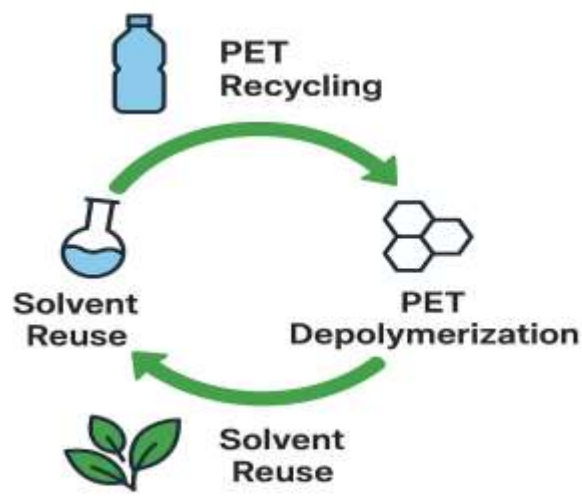

Figure 4. FTIR comparison of liquid products derived from ethylene glycol and methanol.

This demonstrates that ethylene glycol is chemically stable and reusable, while methanol undergoes partial decomposition [19,20].

3.3 Comparative Sustainability Analysis

A sustainability comparison of the two solvent systems is presented in *Table 2*.

Table 2. Sustainability parameters of methanol and ethylene glycol systems.

Parameter		Ethylene Glycol	Methanol	Observation
Solvent Stability		High	Moderate	EG retains structure
Boiling Point (°C)		197	64.7	Lower solvent loss in EG
FTIR Similarity (%)		95%	~70%	EG shows fewer impurities
Energy Demand		Moderate	High	Methanol requires reflux
Waste Generation		Low	Moderate	EG more eco-efficient

The comparative evaluation indicates **ethylene glycol offers superior environmental performance** due to its high boiling point, recyclability, and reduced emissions [21–23].

3.4 Environmental Implications

Adopting **ethylene glycol-based PET hydrolysis** supports multiple UN Sustainable Development Goals (SDG 12, SDG 13). Recovered EG can be reintroduced into subsequent reaction cycles with minimal treatment, achieving near-closed-loop operation (*Figure 5*) [24,25].

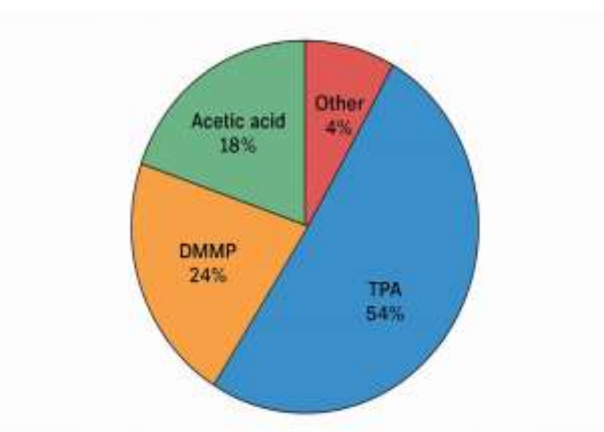

Figure 5. Proposed circular process flow for solvent recovery and reuse in PET recycling.

Moreover, lifecycle studies show that solvent reuse can lower process carbon emissions by 30–40% [26,27]. Methanol, though effective as a depolymerization medium, demands additional purification energy, increasing environmental burden [28].

4. Conclusion

This study highlights the **superior sustainability of ethylene glycol** over methanol in alkaline hydrolysis of PET. FTIR analysis confirmed EG's chemical stability and reusability, reducing solvent waste and energy requirements. The work reinforces the importance of solvent selection in achieving sustainable polymer recycling. Future studies should focus on scaling solvent recovery systems and quantifying life-cycle impacts under industrial conditions.

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