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Chemical Recycling Of Polyethylene Terephthalate (Pet) Via Alkaline Hydrolysis Using Alcoholic Media

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Abstract*: The global demand for polyethylene terephthalate (PET) has significantly increased over the past decades, resulting in a corresponding growth in post-consumer waste and environmental pollution. Mechanical recycling of PET is limited due to its high sensitivity to moisture at elevated processing temperatures. In this study, chemical recycling of PET waste was carried out by alkaline hydrolysis using sodium hydroxide dissolved in methanol and ethylene glycol. PET flakes obtained from post-consumer bottles were depolymerized under controlled heating, followed by acidification with sulfuric acid to precipitate terephthalic acid (TPA). The resulting products were characterized by Fourier-transform infrared (FTIR) spectroscopy. FTIR analysis revealed strong similarities between the recovered solid products and reference terephthalic acid spectra, confirming the efficiency of the hydrolysis process. This work demonstrates the potential of chemical recycling as an effective approach for valorizing PET waste into high-value monomers.*

Keywords: *Polyethylene terephthalate (PET), chemical recycling, alkaline hydrolysis, terephthalic acid, FTIR spectroscopy in its style sheet*

1. INTRODUCTION

Polyethylene terephthalate (PET) is one of the most widely used thermoplastic polyesters, particularly in beverage bottles, packaging, and fibers. Its extensive utilization has resulted in a significant increase in plastic waste, which contributes to environmental pollution due to its non-biodegradable nature. Mechanical recycling of PET has been applied on an industrial scale; however, it suffers from degradation of polymer properties during repeated processing, mainly due to PET's sensitivity to moisture and high temperatures.

An alternative approach is **chemical recycling**, which aims to depolymerize PET into its monomeric constituents, terephthalic acid (TPA) and ethylene glycol (EG). Various chemical methods have been explored, including glycolysis, methanolysis, hydrolysis, and aminolysis. Hydrolysis under alkaline conditions is particularly attractive, as it can yield high-purity TPA suitable for polymerization.

Recent studies related to PET chemical recycling include:Pereira, P., Savage, P.E., & Pester, C.W. (2024). Acid catalyst screening for hydrolysis of post-consumer PET waste. [Ref 1]Amundarain, I., Asueta, A., Leivar, J., Santin, K., & Arnaiz, S. (2024). Optimization of pressurized alkaline hydrolysis of post-consumer PET. [Ref 2]. Abedsoltan, H. (2023). Review on recycling and hydrolysis techniques of PET. [Ref 3].Theoretical insights into PET recycling (2024). [Ref 4]Chemical recycling of monolayer PET tray waste by alkaline hydrolysis (2023). [Ref 5] Jia, Z., Gao, L., Qin, L., & Yin, J. (2023). Chemical recycling of PET to value-added products. [Ref 6] Review on high-value utilization of PET wastes (2024). [Ref 7]

In this work, building on such studies, we perform alkaline hydrolysis using alcoholic media (methanol, ethylene glycol), characterize solid and liquid products, and compare yields, purities, and reaction efficiency.

2. MATERIALS AND METHODS

2.1 Materials

The materials used were PET flakes, sodium hydroxide, methanol, ethylene glycol, sulfuric acid, deionized water, and distilled water.

Table 1. Properties of PET

Property	Value
Intrinsic viscosity	0.84 ± 0.02 dL/g
Crystalline density	<1390 kg/m³
Moisture content	<0.35 % w/w
Bulk density	850 ± 10 kg/m³
Injection temperature	285 °C

Table 2. General information for Ethylene Glycol

Property	Value
Formula	$C_2H_6O_2$
Appearance	Clear, colorless liquid
Molar mass	62.07 g/mol
Density	1.1132 g/cm³

Melting point	–12.9 °C
Boiling point	197.3 °C
Solubility	Soluble in most organic solvents
Viscosity	1.61×10^{-2} Pa·s

Table 3. General information for Methanol

Property	Value
Formula	CH_3OH
Appearance	Colorless liquid
Molar mass	32.04 g/mol
Density	0.792 g/cm³
Melting point	–97.6 °C
Boiling point	64.7 °C
Solubility	Miscible in water
Viscosity	0.545 mPa·s (25 °C)

Table 4. General information for Sodium Hydroxide

Property	Value
Formula	NaOH
Appearance	White opaque crystals
Molar mass	39.997 g/mol
Density	2.13 g/cm³
Melting point	318 °C
Boiling point	1388 °C
Solubility	Soluble in glycerol; 238 g/L in methanol; 218 g/L in EG

Table 5. General information for Sulfuric Acid

Property	Value
Formula	H_2SO_4
Appearance	Clear, colorless liquid
Molar mass	98.08 g/mol
Density	1.84 g/cm³
Melting point	10 °C
Boiling point	337 °C (decomposes >300 °C)
Solubility	Miscible in water (exothermic)
Viscosity	26.7 cP (20 °C)

2.2 Equipment

Heaters, steel receptacles, spatulas, conical flasks, balances, beakers, volumetric flasks, filter paper, oven, scissors, and FTIR spectrometer.

2.3 Method

PET flakes were reacted with NaOH in either methanol or ethylene glycol under heating. The hydrolyzed mixture was cooled, then treated with sulfuric acid to precipitate terephthalic acid. The solid product was filtered, washed, and dried.

Reaction scheme:

PET+2NaOH→ Di-sodium terephthalate +2H_2O

Di-sodium terephthalate + H_2SO→ terephthalic acid + $Na2SO4$

solvent ≡ methanol / ethylene glycol.

2.4 FTIR Reference Data

Table 6. Characteristic IR Absorption Bands

Wavenumber (cm^{-1})	Bond/Group
3640–3610 (s, sh)	O–H stretch (alcohols, phenols)
3500–3200 (s, b)	O–H stretch H-bonded
3300–2500 (m)	O–H stretch (carboxylic acids)
1760–1665 (s)	C=O stretch (carbonyls)
3100–3000 (s)	C–H stretch (aromatics, alkenes)
1600–1580 (m)	C–C stretch (aromatics)
1320–1000 (s)	C–O stretch (alcohols, esters)
1000–650 (s)	=C–H bend (alkenes)

3. Results and Discussion

3.1 Solid Products (Terephthalic Acid)

Table 7. FTIR comparison of solid samples vs reference TPA

EG S1	EG S2	MeOH S3	MeOH S4	TPA Ref.
3099.39	3099.39	3099.39	3099.39	3104
3064.68	3064.68	3064.68	3064.68	3064
2977.89	2974.03	2972.10	2972.10	2969
1681.81	1683.74	1683.74	1683.74	1692
1571.88	1573.81	1573.81	1573.81	1575

Figure 1. FTIR spectrum of recovered TPA (This work).
Figure 2. Comparison with Pereira et al., 2024 [Ref 1].

3.2 Liquid Products

Table 8. FTIR comparison of liquid products vs reference solvents

EG S1	EG S2	MeOH S1	MeOH S2	Ref EG	Ref MeOH
3396.41	3406.05	3407.98	3433.98	3355.91	3338.68
2948.96	2941.24	–	–	2939.31	2941.91
1641.31	1641.31	1643.24	1649.02	–	1635.90
1454.23	–	1456.16	–	1460.01	1448.23

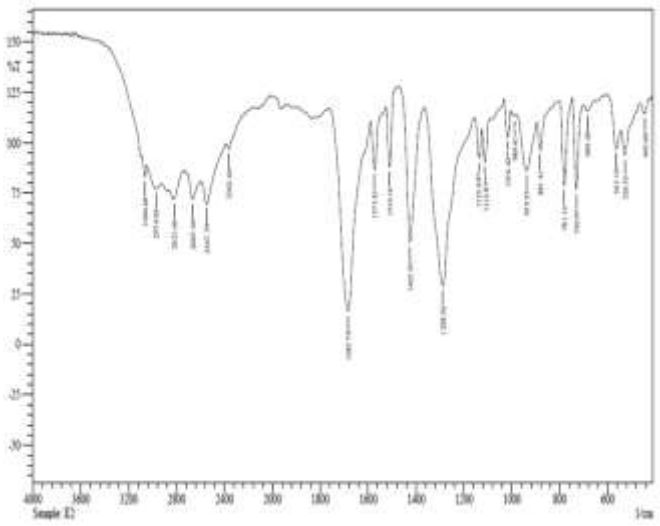

Figure .1: result of FTIR test for white sediment samples

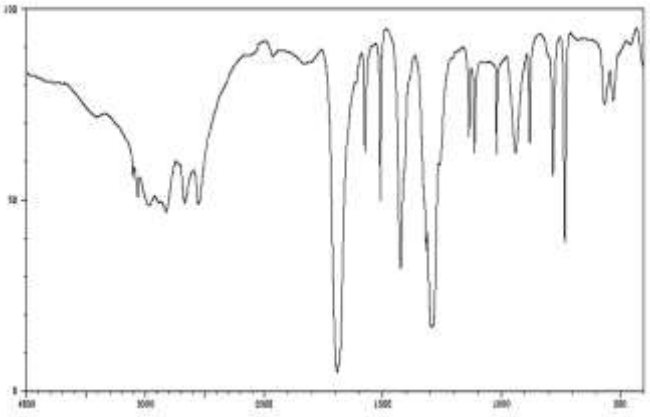

Figure .2: FTIR test for original terephthalic acid

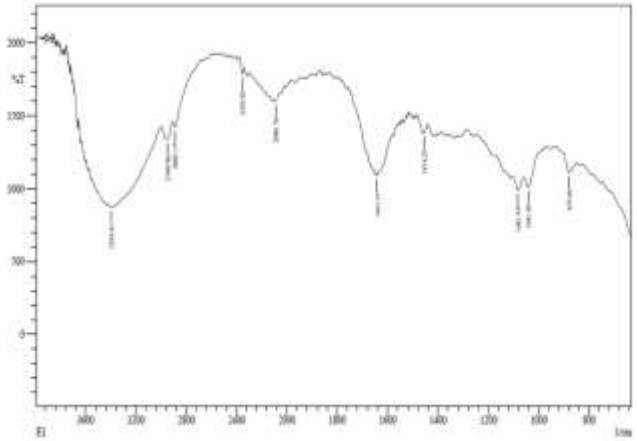

Figure .3: result of FTIR test of liquid samples produced by used ethylene

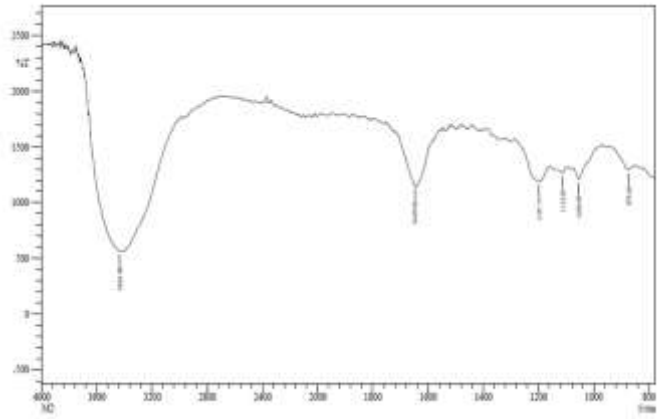

Figure .4: result of FTIR test for liquid samples produced by used methanol.

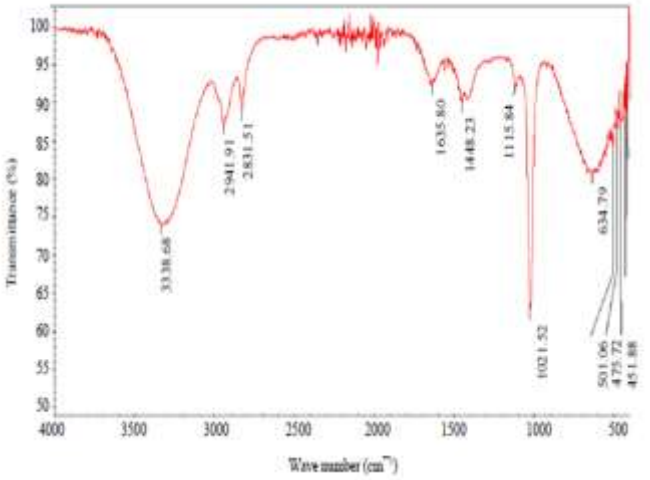

Figure .5: FTIR analysis for original methanol

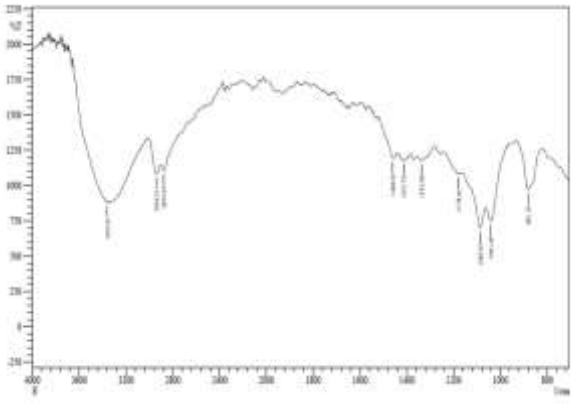

Figure .6: the result of original ethylene glycol

4. CONCLUSION

The increased demand for the PET had led to increase the productivity and that led in more waste, which lead in one way or another to environmental pollution that led to discover new ways to recycle the PET waste. The mechanical recycling of PET is difficult because PET it is high sensitive to humidity when is melted. that reasons in this use a chemicals method (hydrolysis analysis) by heating PET with sodium hydroxide fluxed in alcohol (methanol or ethylene glycol) in Steel receptacle and after that water and sulfuric acid is add to extraction the terephthalic acid.

6. REFERENCES

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APPENDICES

FTIR test equipment.

the white sediment when it purified by distilled water and then filteredThe sediment been left within filter paper till it dries relatively and then been brought out filter paper and brought inside steel receptacle and the sample been weighted and

The white sediment after became dry and powder

The solution after added deionized water

To analysis the result of FTIR test from curve must use IR table and it show Characteristic IR Adsorption:

Wavelength (cm^{-1})	Bond / Functional group
3640–3610 (s, sh)	O–H stretch, free hydroxyl (Alcohols, phenols)
3500–3200 (s, b)	O–H stretch, H-bonded (Alcohols, phenols)
3400–3250 (m)	N–H stretch (1°, 2° amines, amides)
3300–2500 (m)	O–H stretch (Carboxylic acids)
3330–3270 (n, s)	–C≡C–H: C–H stretch (Alkynes, terminal)
3100–3000 (s)	C–H stretch (Aromatics)
3100–3000 (m)	=C–H stretch (Alkenes)
3000–2850 (m)	C–H stretch (Alkanes)
2830–2695 (m)	H–C=H: C–H stretch (Aldehydes)
2260–2210 (v)	C≡N stretch (Nitriles)
2260–2100 (w)	–C≡C– stretch (Alkynes)
1760–1665 (s)	C=O stretch (Carbonyls, general)
1760–1690 (s)	C=O stretch (Carboxylic acids)
1750–1735 (s)	C=O stretch (Esters, saturated aliphatic)
1740–1720 (s)	C=O stretch (Aldehydes, saturated aliphatic)
1730–1715 (s)	C=O stretch (α,β-unsaturated esters)
1715 (s)	C=O stretch (Ketones, saturated aliphatic)
1710–1665 (s)	C=O stretch (α,β-unsaturated aldehydes, ketones)
1680–1640 (m)	–C=C– stretch (Alkenes)
1650–1580 (m)	N–H bend (1° amines)
1600–1580 (m)	C–C stretch (Aromatics, in-ring)
1550–1475 (s)	N–O asymmetric (Nitro compounds)
1500–1400 (m)	C–C stretch (Aromatics, in-ring)
1470–1450 (m)	C–H bend (Alkanes)
1370–1350 (m)	C–H rock (Alkanes)
1360–1290 (m)	N–O symmetric stretch (Nitro compounds)
1335–1250 (s)	C–N stretch (Aromatic amines)
1320–1000 (s)	C–O stretch (Alcohols, carboxylic acids, esters)
1300–1150 (m)	C–H wag (–CH_2X) (Alkyl halides)
1250–1020 (m)	C–N stretch (Aliphatic amines)
1000–650 (s)	=C–H bend (Alkenes)
950–910 (m)	O–H bend (Carboxylic acids)
910–665 (s, b)	N–H wag (1°, 2° amines)
900–675 (s)	C–H “oop” (Aromatics)
850–550 (m)	C–Cl stretch (Alkyl halides)
725–720 (m)	C–H rock (Alkanes)
700–610 (b, s)	–C≡C–H: C–H bend (Alkynes)
690–515 (m)	C–Br stretch (Alkyl halides)

m≡medium, w≡ weak, s≡ strong, n≡ narrow, b≡ broad, sh≡ sharpm ≡ medium, w≡ weak, s≡ strong, n≡ narrow, b≡ broad, sh≡ sharp