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CHEMICAL UPCYCLING OF PET WASTE FOR TEREPHTHALIC ACID RECOVERY: A SUSTAINABLE MATERIALS PROCESSING APPROACH

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ABSTRACT

Polyethylene terephthalate (PET) waste creates significant environmental problems because traditional mechanical recycling often leads to lower-quality materials. Chemical upcycling gives a different approach by enabling the recovery of materials down to their monomer level and promoting closed-loop recycling. This study demonstrates the chemical upcycling of post-consumer PET waste into terephthalic acid (TPA) using hydrolysis with sulfuric acid, followed by alkaline purification and acid precipitation. How the concentration of sulfuric acid (60-98%) and the reaction time (30-120 minutes) influenced TPA yield was systematically evaluated in a lab setting. Optimized results came from using 90% acid concentration for 90 minutes, resulting in a maximum of 4.32 grams of TPA from 10 grams of PET, which is about 50% of the theoretical yield. The recovered TPA appeared as a white crystalline solid, consistent with the physical properties of TPA. The results indicate that the process is straightforward, catalyst-free, and reproducible for material recovery. This study underscores the viability of chemical upcycling as an effective way to manage PET waste within a circular economy framework.

KEYWORDS: *PET Waste, Chemical Upcycling, Terephthalic Acid, Sustainable Manufacturing, Materials Recovery*

Article History

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INTRODUCTION

After-use plastic waste has increased due to the extensive use of polyethylene terephthalate (PET) in textiles beverages containers and packaging. The disposal of PET causes major environmental problems including landfill and accumulation and ecosystem pollution due to durability and difficulty decomposing in environment. Effective recycling techniques are essential to reduce the negative environmental effects of PET waste.

The popular technique for handling PET waste is traditional mechanical recycling. However, the polymer chains are broken down by polymer chains, that leads to weaker material and limiting how many times it can be recycled. This process, known as down cycling, the economic value of recycled PET products possesses an impact on long-term viability of mechanical recycling

By breaking down PET into its individual monomers, chemical upcycling provides an alternate technique that enables molecular-level material recovery. Some of the various chemical recycling methods such as hydrolysis, glycolysis and methanolysis. Acid hydrolysis is a relatively easy method to do in a lab with standard reagents. Terephthalic acid (TPA) is a crucial monomer for the production of new PET is recyclable and recovered, enabling closed-loop recycling and

to encourage a circular materials economy

PET sustainable recycling has been extensively investigated but many of the techniques that were recently reported call over complicated reactor systems, extremely high pressures and temperatures, catalysts. Their application to academic or small-scale project is prohibited by these factors. Inexpensive, accessible and reliable chemical upcycling techniques that enable a systematic evaluation of important process factors and material recovery rates are still desirable.

When allowing material recovery from polymer waste using an affordable lab-scale chemical method, this process supports sustainable manufacturing. This study uses sulphuric acid to hydrolyse post-consumer PET waste, followed by alkaline purification and acid precipitation to upcycle into a terephthalic acid. In order to determine the ideal conditions that achieve a balance between process simplicity and material breakdown efficiency, the study thoroughly investigates the effects of acid concentration and reaction time on TPA yield.

METHODOLOGY

Materials and Equipment

PET bottles were previously being utilized , collected and carefully cleaned to get free of contaminants and labels. They were subsequently dried and chopped into small flakes. For depolymerisation concentrated sulphuric acid (60-98%) was used. For alkaline purification, a 15% w/v potassium hydroxide solution was worked and for acid precipitation, 37% hydrochloric acid was used. Distilled water and methanol were used for dilution and working. Every chemical used was of high quality for analytical reagents and did not require any further purification. A drying oven, a separating funnel, a vaccum filtration unit and hot plate with a magnetic stirrer were every component of the experimental setup.

Acid Hydrolysis of PET

Concentrated sulphuric acid and distilled water were combined and ten grams of PET flakes were added slowly while constantly stirring the mixture. For an hour, the mixture was warmed and maintained at that temperature. Acid-catalysed ester bond cleavage led PET to soften and breakdown during this time producing ethylene glycol and intermediates based on terephthalic acid. After the reaction attained a specific temperature.

Alkaline Purification and Acid Precipitation

The depolymerized reaction mixture was diluted with distilled water. Then, the solid residue was treated with a 15% potassium hydroxide solution. This step converted terephthalic acid into soluble potassium terephthalate, which allowed for the removal of leftover impurities. Insoluble residues were separated by filtration. Next, the clear alkaline filtrate was acidified with hydrochloric acid while stirring. This led to the precipitation of terephthalic acid as a white solid. The precipitate was recovered by vacuum filtration, washed with distilled water to remove remaining salts, and dried in an oven until it reached a constant weight.

Figure 1: Experimental Sequence for PET Depolymerisation and Terephthalic Acid Recovery via Sulphuric Acid Hydrolysis, Potassium Terephthalate Formation and Acid Precipitation.

RESULTS AND DISCUSSION

Effect of Sulfuric Acid Concentration

The Distilled water was employed to dilute the depolymerized reaction mixture. A 15% potassium hydroxide solution was subsequently utilized to the solid residue. Terephthalic acid was modified into soluble potassium of terephthalate in this step permitting the removal of any other substances. Filtration was employed to separate the insoluble residues. Hydrochloric acid was subsequently added to the clear alkaline filtrate while stirring. Terephthalic acid resulted as a white solid as a result. After obtaining the precipitate with vaccum filtration and cleaning it with distilled water to get rid of the remaining salts, it had been dried in an oven until its weight kept constant.

Table 1: Effect of Acid Concentration on TPA Yield

H2SO4 Concentration (%)	Weight of TPA Obtained (g)	% Yield of TPA
60	3.8	44%
70	4.5	52%
80	5.6	65%
90	5.8	68%
98	5.7	66%

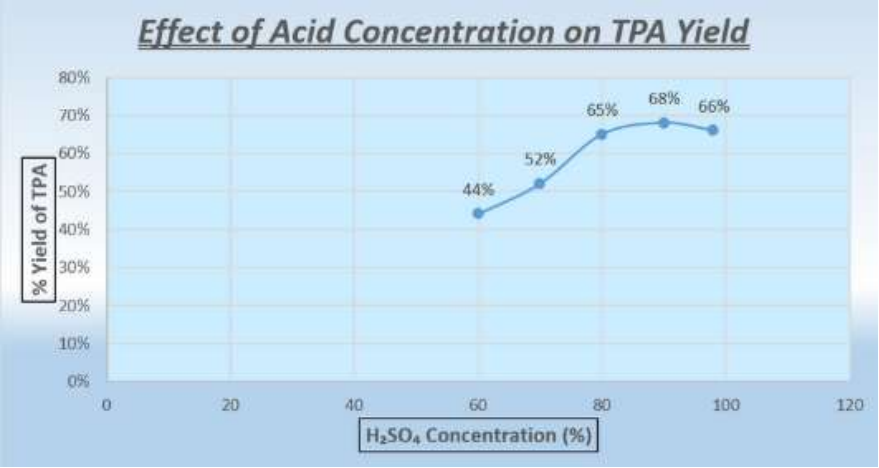

Figure 2: Effect of Acid Concentration on TPA Yield.

Effect of Reaction Time

Reaction The rate of PET depolymerisation was significantly influenced by reaction time. Up to 90 minutes of reaction-time led to an increase in TPA yield, which suggests constant ester bond cleavage. The yield only barely raised after this, indicating that the reaction was almost complete. This suggests that conversion efficiency is not significantly raised by longer heating.

Table 2: Reaction Time Analysis

REACTION TIME (MIN)	TPA YIELD (%)
30	40%
60	65%
90	70%
120	72%

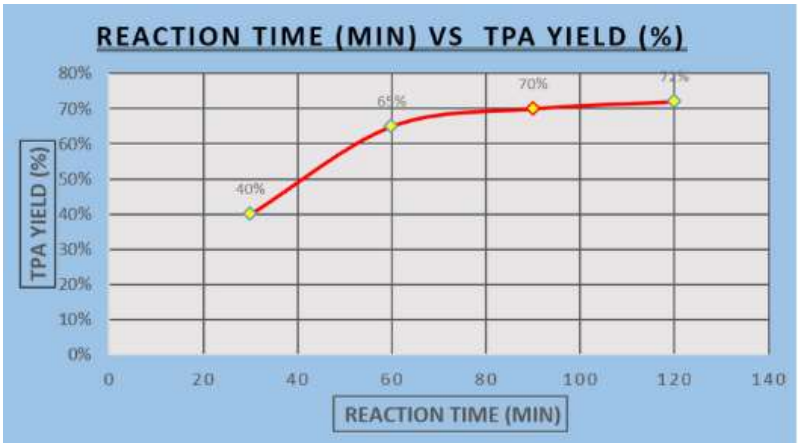

Figure 3: Reaction Time (min) Vs TPA Yield (%).

Yield Analysis

For Based on its stoichiometric composition the theoretical yield of terephthalic acid has been found to be 8.63g for an initial PET mass of 10g. 4.32g or roughly 50% of the theoretical yield was the largest yield from experiments was measured. The partial solubility of TPA in water, incomplete conversion of intermediates and material loss during filtration and washing are the causes of the difference between theoretical and experimental yields. All of the losses the outcomes demonstrate the viability and reproducibility of the suggested laboratory-scale chemical upcycling technique.

CONCLUSION

This Process demonstrates the chemical upcycling of post-consumer PET waste into terephthalic acid through hydrolysis mediated by sulphuric acid, followed by acid precipitation and alkaline purification. Without the use of high-pressure systems or catalysts, the process is carried out in a moderately heated laboratory. It makes use of standard equipment and easily accessible reagents. In comparison to the theoretical yield the ideal conditions resulted to a recovery of roughly 50% of the terephthalic acid. These results highlight the possibility of chemical upcycling as a renewable materials recovery strategy that supports circular economy principles beyond traditional mechanical recycling even though further optimization and analysis are required.

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