Investigation of Rapid Chemical Recycling of Waste Polyethylene Terephthalate Under Microwave Effect Using Calcined Dolomite as Catalyst

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Abstract: According to the United Nations, our planet produces an average of 430 million tons of plastic annually. A significant portion of the environmental pollution caused by the use of plastics is due to polyethylene terephthalate (PET) used in short-lived packaging products. Various studies have been conducted with the aim of recycling or converting PET waste into useful products. In addressing the dual environmental challenges posed by waste PET and dolomite, this study innovates in the realm of sustainable recycling practices. We explore the efficiency of a solid catalyst derived from waste dolomite in catalyzing the hydrolysis of waste PET. This research not only showcases the catalytic prowess of waste-derived dolomite in breaking down PET into its constituent monomers but also highlights the process's optimization for maximum efficiency. Through careful analysis and optimization of various parameters, including Temperature, reaction time, and catalyst concentration, we achieve an unprecedented conversion rate, illustrating the potential of this method in contributing to the circular economy. Our findings offer a groundbreaking approach to PET waste management, emphasizing the importance of sustainability and innovation in tackling environmental pollution. Dolomite is a widely available ore with a composition of $CaCO_3.MgCO_3$. After calcination, the obtained CaO-MgO mixture can be used to recycle PET via hydrolysis. In this study, Temperature (140 °C, 150 °C, 160 °C), ethanol concentration (0%, 5%, 10%), potassium hydroxide concentration (0%, 5%, and 10%), and the amount of calcined dolomite (0 g/100 mL, 0.03 g/100 mL, and 0.06 g/100 mL) parameters were selected for the PET hydrolysis process conducted in a short time using a microwave digestion system. The Taguchi L_9 experimental design was applied, and all experiments were repeated four times.

1. INTRODUCTION

In the process of natural stone production, the cutting operations carried out in both quarries and manufacturing plants result in significant amounts of waste material, which can represent between 50% and 60% of the total stone processed (1). The variability in waste generation is influenced by several factors, including the stone's inherent mineralogical properties, the presence and pattern of discontinuities and cracks, and the specific methodologies employed in the production and processing stages. The waste produced within these settings is predominantly categorized based on its size: into coarse or large fragments and fine particulates (2).

The coarse or large waste fragments, which make up about 40% of the quarry's output, vary significantly in size (from a few centimeters to several meters) and can adopt a variety of shapes. This diversity in size and shape underscores the complexity of managing such waste efficiently (3). On the other hand, the fine waste generated, particularly from the processing of natural stones in factories, is mainly comprised of powder-like substances with particle sizes falling below 150 micrometers. This fine waste is mechanically

collected and transported to disposal sites, often necessitating the use of loaders for loading onto trucks, followed by transport to designated dumping areas (4).

The management and disposal of natural stone waste pose logistical and environmental challenges. Unused agricultural lands, often located at considerable distances from natural stone operations and deposits, are frequently repurposed as sites for waste disposal. This practice, however, raises concerns regarding the optimal and sustainable use of land resources. Agricultural lands, even if currently unutilized, should ideally be preserved for agricultural purposes or land conservation efforts rather than being transformed into waste disposal sites. Moreover, the practice of utilizing operational sites as disposal areas can significantly hinder operational efficiency by reducing maneuverability within these spaces. Additionally, opting for waste disposal in alternative locations introduces extra logistical burdens, primarily due to the transportation costs involved.

Environmental concerns associated with natural stone waste are multifaceted, encompassing issues such as landscape alteration, soil displacement, deterioration of water quality in both surface and underground sources, and contributions to air and visual pollution. These impacts underscore the urgency of adopting more sustainable waste management practices within the natural stone industry (5).

Recognizing the substantial environmental footprint and economic implications of such waste, there's a growing emphasis on repurposing natural stone waste into valuable secondary products (6). This waste is increasingly being utilized in various applications, including but not limited to the creation of building materials, the construction of roads (7,8), the production of concrete (9), as abrasives (10), the erection of flood prevention barriers (11), for soil neutralization purposes (12), and in the manufacturing of cement (9), and composites (13). Moreover, its use in filtration processes and the feed industry represents innovative approaches to waste valorization, contributing to a more circular economy where

waste is transformed into resources, thus alleviating environmental impacts while simultaneously enhancing production sustainability in the natural stone sector (14).

The escalating production and disposal of PET pose a dual challenge of environmental pollution and resource wastage, with millions of tons of PET waste accumulating in landfills and natural habitats each year. This situation is exacerbated by the durable nature of PET, which resists biodegradation, leading to prolonged environmental persistence (15). Given these concerns, there is an urgent need for more effective recycling methods that not only mitigate environmental harm but also reclaim the value embedded in waste PET.
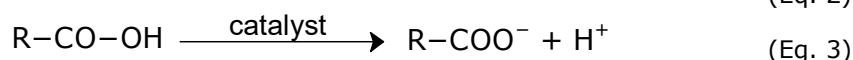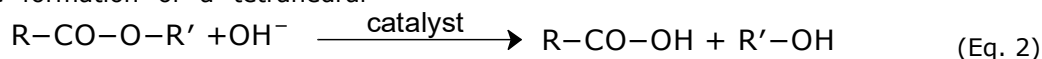
Chemical recycling, particularly hydrolysis, presents a viable alternative to mechanical recycling, offering the potential to break down PET into its constituent monomers, which can be reused to produce new PET or other valuable products. This process not only diverts PET from landfills but also reduces the reliance on virgin materials, aligning with the principles of a circular economy. However, conventional hydrolysis processes often rely on expensive and environmentally harmful catalysts, which can limit their sustainability and economic viability (16).
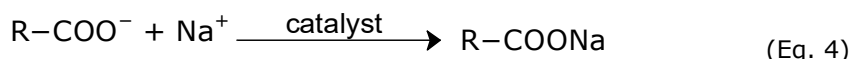
PET hydrolysis is a chemical process in which the PET polymer interacts with water molecules to break down into its fundamental monomers. This process occurs at high temperatures and pressure under acid, base, or neutral catalysis (17). In acidic hydrolysis, the ester bonds in PET react with a strong acid, such as sulfuric acid (H_2SO_4), to release terephthalic acid ($HOOCC_6H_4COOH$ - TPA) and ethylene glycol ($HOCH_2CH_2OH$ - EG) monomers. In basic hydrolysis, the use of a base like sodium hydroxide (NaOH) causes the breakdown of PET into sodium salts and EG. The TPA derivatives and EG obtained from these reactions are essential components that can be reused in new PET production or other chemical processes. PET hydrolysis is a crucial step in the recycling of polymer waste (18). The equation for the general hydrolysis reaction is given in Equation (1).

$$(COC_6H_4COOCH_2CH_2O)_n + 2n\ H_2O \xrightarrow{\text{catalyst}} n\ (HOOCC_6H_4COOH) + n\ (HOCH_2CH_2OH) \quad \text{(Eq. 1)}$$
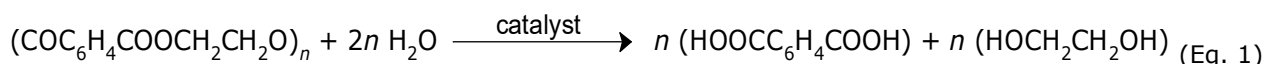
Equations 2-4 show the mechanism of how PET breaks down into TPA and EG via basic hydrolysis in the presence of NaOH. The OH^- ion from NaOH acts as a nucleophile and attacks the carbonyl carbon in the ester group of the PET polymer chain. This attack results in the formation of a tetrahedral

intermediate. The tetrahedral intermediate breaks down, resulting in the cleavage of the ester bond. This forms EG and a carboxylate ion ($R\text{-}COO^-$). The carboxylate ion ($R\text{-}COO^-$) reacts with Na^+ from the NaOH solution to form sodium terephthalate (19).

$$R{-}CO{-}O{-}R' + OH^- \xrightarrow{\text{catalyst}} R{-}CO{-}OH + R'{-}OH \quad \text{(Eq. 2)}$$

$$R{-}CO{-}OH \xrightarrow{\text{catalyst}} R{-}COO^- + H^+ \quad \text{(Eq. 3)}$$

$$R-COO^- + Na^+ \xrightarrow{\text{catalyst}} R-COONa \qquad \text{(Eq. 4)}$$

In the overall reaction, the PET polymer chain is fully broken down into sodium TPA and EG:

$$(COC_6H_4COOCH_2CH_2O)n + 2n\text{NaOH} \xrightarrow{\text{catalyst}} n(\text{NaOOCC}_6H_4\text{COONa}) + n(\text{HOCH}_2\text{CH}_2\text{OH}) \qquad \text{(Eq. 5)}$$
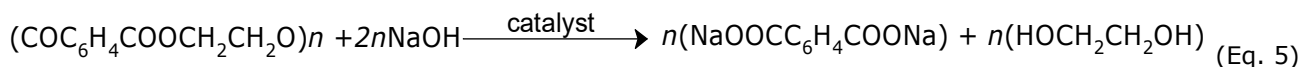
In response to these challenges, this study explores the use of waste dolomite as a novel, eco-friendly catalyst for the hydrolysis of waste PET. Dolomite, a sedimentary carbonate rock, is abundant in nature and often regarded as a waste byproduct in various industrial processes (20). In PET recycling, the use of $CaCO_3$ and $MgCO_3$, the chemicals that make up dolomite, is commonly considered a filler to enhance the mechanical properties of plastics, reduce processing time, and decrease costs (21). Additionally, these substances can improve the thermal stability and heat resistance of PET, thereby expanding the application areas of recycled PET (22). By repurposing this readily available material, the study not only seeks to enhance the environmental and economic efficiency of PET hydrolysis but also to promote the valorization of waste materials as resources for sustainable development.

The hydrolysis of PET is a well-studied process with applications in recycling and waste management. Both acid and base can catalyze the hydrolysis of PET, resulting in the production of TPA and EG (23). Research has demonstrated that incorporating metal hydroxides like sodium or potassium hydroxide through melt mixing can enhance the hydrolysis of PET (24). Studies have also explored the kinetics of PET hydrolysis using acids such as nitric acid and sulfuric acid, emphasizing the significance of temperature and catalysts in the process (25).

Various factors, including the presence of cellulose and polypropylene, can influence the efficiency of PET hydrolysis (26). Enzymatic hydrolysis of PET, utilizing enzymes like cutinase, has been investigated for waste stream management (27). Additionally, the use of ionic liquids as solvents and catalysts has shown promise in improving the conversion and yield of TPA during PET hydrolysis (28).

The depolymerization of PET through hydrolysis has been studied under different temperatures and conditions to optimize the process for industrial applications (29). Research has also delved into hydrolyzing PET below its melting range to understand the impact of factors like diffusion and crystallinity on reaction kinetics (30). Alkaline hydrolysis and neutral hydrolysis have been explored as methods to break down PET into its monomers, such as TPA and EG (31,32).

In conclusion, the hydrolysis of PET is a multifaceted process influenced by parameters like temperature, catalysts, and reaction conditions.

Understanding these mechanisms and factors is crucial for the development of effective recycling and waste management strategies.

The research methodology in this study involves a comprehensive experimental design to evaluate the catalytic performance of calcined dolomite in the hydrolysis of PET, examining factors such as temperature, catalyst loading, and reaction time. The study also employs statistical analysis to optimize the hydrolysis conditions, aiming to maximize the yield of TPA, a key monomer derived from PET. Through this rigorous analysis, the study endeavors to establish a scalable and sustainable model for chemical recycling, contributing valuable insights to the fields of waste management and green chemistry.

By addressing the environmental impact of PET waste and demonstrating the feasibility of using waste dolomite as an effective catalyst, this research not only advances the scientific understanding of chemical recycling but also highlights the broader potential for integrating waste valorization into environmental sustainability strategies. Ultimately, this study underscores the importance of innovative approaches to waste management, encouraging further exploration of waste-to-resource technologies that can contribute to the transition toward a more sustainable and circular economy.

2. MATERIALS AND METHODS

2.1. Materials
The used KOH (≥85% KOH basis, pellets, white) was obtained from Sigma-Aldrich, and ethanol (absolute) from Isolab. The conductivity value of the used pure water was at most 10 µS, produced using a Merck Millipore Essential pure water device. The dolomite used in the experiment was procured from Doltaş Mining Co. located in İzmir. Crushed, ground, and sieved dolomite has been calcined by burning in a furnace at 1000 °C for 5 hours to be used as a catalyst. Waste PET was obtained by collecting PET used in daily life. After being washed with pure water, the waste PET was dried, then crushed, divided into pieces, and sieved. Pieces in the range of 2-3 mm were used in the experiments. Hydrolysis experiments were conducted using a Microwave Digestion System, speedwave XPERT.

2.2. Methods
In the study, temperature (140 °C, 150 °C, 160 °C), ethanol (0 mL, 5 mL, 10 mL), KOH (0 g, 5 g, 10 g), and catalyst (0 g, 5 g, 10 g) were selected as parameters (Table 1).

During the experiment, solutions prepared were taken and placed into PET, and a catalyst was added. The reactor, sealed to prevent leakage, was placed in a microwave heating setup and heated to the temperature specified in the experiment design. Once the desired temperature was reached, it was maintained for 15 minutes and then allowed to cool down.

Table 1: Factors and levels used in the Taguchi L_9 design experiments.

Factors	Level 1	Level 2	Level 3
Temperature (°C)	140	150	160
Ethanol (mL/100 mL)	0	5	10
KOH (g/100 mL)	0	5	10
Catalyst (g/100 mL)	0	0.03	0.06

The Taguchi L_9 experimental design method was employed in the experiments, serving as a strategic framework for the systematic analysis of multiple variables simultaneously. This approach is particularly beneficial in reducing the complexity and resource requirements of experimental studies, as it allows for the efficient identification of the most influential factors and their optimal settings. In the context of this study, the Taguchi L_9 design was meticulously chosen to investigate the impact of four distinct factors, each varied across three different levels, thereby ensuring a comprehensive exploration of the experimental space with a limited number of runs. Specifically, the design encompassed 4 factors, which were temperature, ethanol concentration, KOH quantity, and the amount of catalyst, all considered critical to the process under study. Each of these factors was tested at three levels to ascertain their individual and combined effects on the experimental outcomes. To enhance the reliability and validity of the results, every experimental condition specified within the Taguchi L_9 design was replicated at least four times. This rigorous repetition serves to mitigate the potential influence of experimental errors and variability, providing a robust dataset for analysis. The structure and specific assignments of these factors and levels within the Taguchi L_9 experimental design are detailed in Table 2, offering a clear roadmap for the execution and analysis of the experiments.

Table 2: Taguchi L_9 experimental design of hydrolysis reaction with waste PET.

Run	Temperature (°C)	Ethanol (mL/100 mL)	KOH (g/100 mL)	Catalyst (g/100 mL)
1	140	0	0	0
2	140	5	5	0.03
3	140	10	10	0.06
4	150	0	5	0.06
5	150	5	10	0
6	150	10	0	0.03
7	160	0	10	0.03
8	160	5	0	0.06
9	160	10	5	0

3. RESULTS AND DISCUSSION

As a result of the experiment, the amounts of PET that did not react were measured, and the conversion rates were calculated using the formula given in Equation 6. The calculation results based on the data from the experiments are summarized in Table 3. Since four repetitions were performed, the obtained conversion percentages are reported in four separate columns as: R1, R2, R3, and R4

$$Conversion\,\% = \frac{Initial\,PET\,amount - Remaining\,PET\,amount}{Initial\,PET\,amount} \times 100 \qquad \text{(Eq. 6)}$$

Table 3: The conversion percentages obtained from the experiments.

Exp. Number	Temperature (°C)	Ethanol (mL/100 mL)	KOH (g/100 mL)	Cat. (mg/L)	R1 (X%)	R2 (X%)	R3 (X%)	R4 (X%)
1	140	0	0	0	3.75	4.28	4.02	4.06
2	140	5	5	0.03	15.55	16.01	15.91	15.41

3	140	10	10	0.06	61.55	57.44	59.31	60.43
4	150	0	5	0.06	21.46	20.67	19.75	21.85
5	150	5	10	0	62.16	62.59	67.31	61.70
6	150	10	0	0.03	3.62	3.97	4.50	5.31
7	160	0	10	0.03	66.94	66.41	69.27	68.13
8	160	5	0	0.06	3.43	4.95	4.74	4.40
9	160	10	5	0	32.33	36.00	36.21	34.51

The signal-to-noise (S/N) ratios were calculated from the obtained conversion rates using the "larger is better" approach and are provided in Table 4.

Table 4 presents the average effect of each parameter's variation on the signal-to-noise (S/N) ratio. The data reveals insightful trends about the factors influencing process efficiency and outcome quality. Temperature demonstrates a steady increase in the S/N ratio from 23.84 at Level 1 to 26.65 at Level 3, signifying that elevated temperatures positively affect the outcome, with a moderate difference of 2.82 indicating its impact. Similarly, Ethanol shows an increase in S/N ratio from 25.03 to 26.27, marking a subtle yet positive influence of increased ethanol concentration, albeit with a smaller difference of 2.10. Notably, KOH stands out for its significant impact, with the S/N ratio soaring from 12.38 to 36.05 between the extreme levels, underscoring a robust effect of KOH concentration on the process, evidenced by a substantial difference of 23.67.

Table 4: Response table for signal to noise ratios*.

Level	Average S/N Ratios			
	Temperature	**Ethanol**	**KOH**	**Catalyst**
1	23.84	25.03	12.38	26.30
2	24.98	24.17	27.04	24.35
3	26.65	26.27	36.05	24.82
Difference	2.82	2.10	23.67	1.95
Ranking	2	4	1	3

*Larger is better.

In contrast, Catalyst's influence is more moderate, with S/N ratios ranging from 26.30 to 24.82 and a difference of 1.95, indicating a beneficial yet comparatively lesser impact than temperature and much less than KOH. The ranking of factors by their influence on the S/N ratio places KOH at the pinnacle, followed by temperature, catalyst, and ethanol, in descending order of impact. This meticulous analysis aids in pinpointing the critical factors that markedly influence the desired outcome. Concentrating on the highest-ranked factors enables process optimization to attain superior performance. Employing a statistical methodology furnishes a structured evaluation, offering definitive guidance for ameliorating process efficiency or enhancing the quality of outcomes. For a clearer understanding of Table 4, the data are graphically represented in Figure 1.

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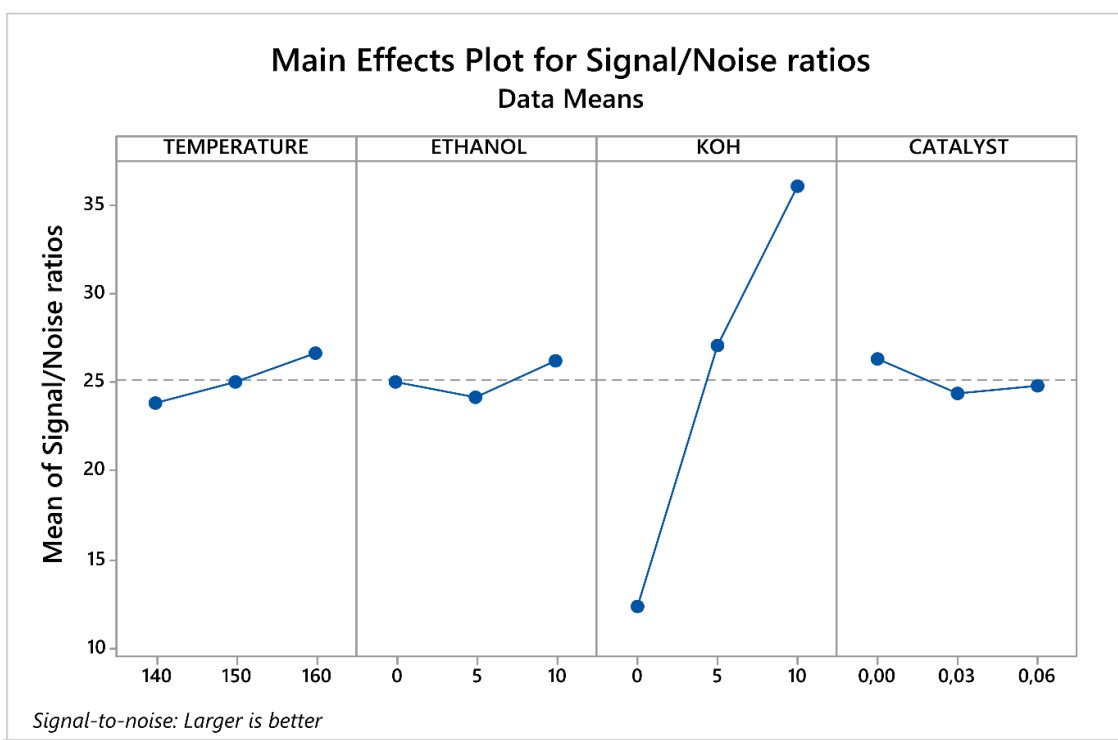
Figure 1: Main effects plot for S/N ratios.

Due to the difficulty in interpreting S/N ratios, average conversion rates corresponding to each parameter level can be calculated using the S/N ratios (Table 5).

Table 5: Response Table for Means*.

Level	Average Conversion Percentages (%)			
	Temperature	**Ethanol**	**KOH**	**Catalyst**
1	26.477	30.883	4.253	34.077
2	29.574	27.847	23.805	29.252
3	35.610	32.932	63.603	28.332
Difference	9.133	5.085	59.351	5.745
Ranking	2	4	1	3

*Larger is better.

The analysis for Table 5 reveals how each parameter distinctly influences the conversion rate, illustrating the complexity of the process and the importance of precise control over conditions. Temperature demonstrates a clear trend of increasing conversion percentages with rising levels, illustrating a substantial effect on the process's efficiency. The leap from 26.477% at the lowest level to over 35% at the highest signifies the critical role temperature plays, positioning it as a pivotal factor for optimizing outcomes.

The efficiency of the PET hydrolysis process is indeed significantly influenced by temperature. Several studies have demonstrated the impact of temperature on the hydrolysis of PET. In one study, the temperature had a significant impact on the hydrolysis of PET. The degradation follows an Arrhenius equation, which relates the degradation rate to temperature and relative humidity. Hydrolysis of PET is accelerated at higher temperatures, leading to increased chain scission and crystallinity changes. The model presented in the paper suggests that the combination of temperature and RH directly affects the rate of PET degradation (33).

Similarly, in a review by Geyer and others (2016), while discussing chemical methods for PET recycling, the dependence of these processes on temperature is emphasized. According to this study, researchers working with different methods reported that increasing temperatures improved the efficiency of PET hydrolysis. Only in enzymatic reactions was it shown that deviations from the optimal temperature range reduced the efficiency of the hydrolysis reaction (34). Moreover, a study by Conroy and Zhang (2024) (35) confirms the

continued interest in PET hydrolysis, emphasizing that the effect of temperature on PET hydrolysis is a critical factor for efficient polymer breakdown. According to the study, increasing temperatures significantly improve reaction kinetics, lower activation energies, and lead to rapid PET decomposition. As a result, Temperature stands out as one of the most important factors for effective hydrolysis in PET recycling (35).

KOH, on the other hand, showcases an even more pronounced impact, with its conversion percentage soaring at the highest level, emphasizing its paramount importance in the reaction mechanism. This dramatic increase points to KOH's efficacy in facilitating the conversion process, highlighting it as a primary lever for enhancing performance.

KOH has been recognized for its effectiveness in facilitating the PET hydrolysis conversion process. Studies have shown that KOH plays a crucial role in enhancing the hydrolysis of PET waste. Karayannidis et al. (2002) investigated the recycling of PET through alkaline hydrolysis and highlighted the use of KOH in the process, demonstrating its efficacy in promoting the conversion of PET into valuable products like TPA (36).

Moreover, Adibfar et al. (2014) (37) found that KOH-activated PET showed superior adsorption properties for molecules of varying sizes, indicating the effectiveness of KOH in modifying PET for enhanced performance (37). Additionally, Yoshioka et al. (2003) (38) conducted a study on the conversion of PET into oxalic acid and TPA using alkaline solutions, showcasing the role of KOH in the

hydrolysis process (38). Furthermore, Rubio Arias et al. (2022) (39) developed a KOH-in-methanol hydrolysis process for the selective depolymerization of PET and polycarbonate, emphasizing the efficiency of KOH in achieving instantaneous PET hydrolysis (39). These findings collectively underscore the significance of KOH in promoting the hydrolysis and conversion of PET waste into valuable products, highlighting its role as an effective catalyst in the PET recycling industry.

Ethanol and Catalyst, while contributing to variations in conversion rates, exhibit a more nuanced influence compared to the stark effects of Temperature and KOH. Ethanol's moderate variation suggests its role is significant but secondary in optimizing the process. The effect of ethanol on PET hydrolysis is already known in the literature (24). The Catalyst's impact, being the least pronounced, indicates its supportive but less critical role in the conversion process.

Overall, this analysis not only ranks the parameters by their influence on conversion rates but also underscores the importance of a balanced approach in managing these variables to achieve optimal results. Adjustments in KOH concentration and temperature management emerge as key strategies for improving conversion efficiencies, with considerations for Ethanol and Catalyst providing additional fine-tuning capabilities. This statistical insight forms a foundation for targeted optimizations, guiding efforts towards achieving the most efficient and effective conversion process. To facilitate a better understanding of this table, the data are presented graphically in Figure 2.
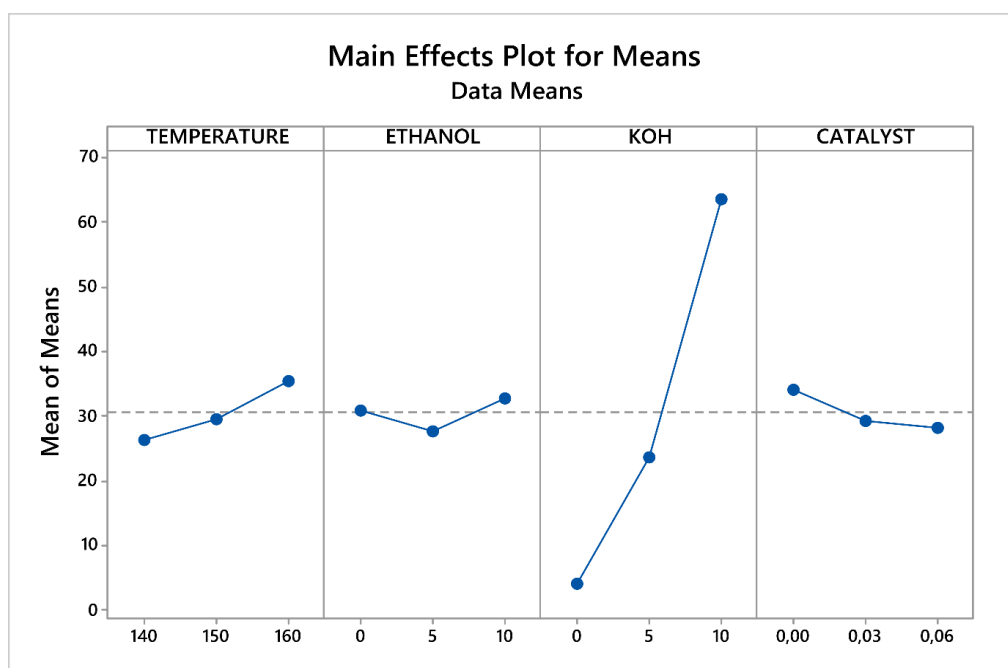
Figure 2: Main effects plot for Means.

In Figure 2, the average conversion percentages corresponding to the actual levels of the parameters can be observed.

A hypothesis test and analysis of variance (ANOVA) were conducted to understand whether the parameters used in the experiment had a significant effect on the response (Table 6). In hypothesis testing, the null hypothesis assumes that all means are equal, meaning the factors do not significantly affect the response. The null hypothesis is accepted if the p-value calculated at a 95% confidence interval is greater than 0.05, and it is rejected if the p-value is less than 0.05 (the H_1 hypothesis cannot be dismissed).

H_0: $\mu_1 = \mu_2 = \mu_3 \ldots = \mu_k$

H_1: The means are not equal

Table 6, detailed here, offers a profound insight into the statistical underpinnings of an experiment aimed at deciphering the effects of various factors (Temperature, Ethanol, KOH, and Catalyst) on a specified outcome. This statistical examination, coupled with an overarching regression model, endeavors to unravel the intricacies of data variability, providing a systematic approach to quantify the influence of each factor.

Table 6: Analysis of Variance (ANOVA) results.

	Degrees of Freedom	Adjusted Sum of Squares	Adjusted Mean Squares	F-value	P-value
Regression	4	21858.9	5454.7	161.42	0.000
Temperature	1	500.5	500.5	14.78	0.001
Ethanol	1	25.2	25.2	0.74	0.395
KOH	1	21135.1	21135.1	624.31	0.000
Catalyst	1	198.0	198.0	5.85	0.022
Error	31	1049.5	33.9		
Residual	4	999.4	249.9	134.84	0.000
Pure Error	27	50	1.9		
Total	35	22908.3			

The Degrees of Freedom (DF) serves as a foundational metric, delineating the scope within which the data can fluctuate. With the regression model boasting 4 degrees of freedom, mirroring the quartet of examined factors, and the error manifesting 31 degrees, this delineation underscores the residual variance unaccounted for by the model, thus spotlighting areas of further investigation or model refinement.

The Adjusted Sum of Squares, a critical statistical measure, quantifies the total variance attributable to each factor, meticulously adjusted for their respective degrees of freedom. KOH's notably high value in this metric signifies its predominant role in dictating the data's variance, suggesting its paramount importance in the experimental outcome.

Further dissecting this variance, the Adjusted Mean Squares metric offers an average variance per factor, with KOH again emerging as the pivotal influence, showcasing its substantial impact on the experimental results. This is further corroborated by the F-value, a statistical test for assessing the null hypothesis' viability—that a factor bears no impact. KOH's exceptional F-value not only refutes this

hypothesis but also heralds its critical role in the dependent variable's variation.

The P-value metric, reflecting the likelihood of observing the data under the null hypothesis, fortifies the statistical argument with its threshold significance. Both the overall regression and the exceptionally low p-values for KOH solidify their undeniable effects on the outcome, while the higher p-value for Ethanol suggests a statistically insignificant effect.

This statistical narrative is further enriched by the analysis of "Error" and "Total" variance, with "Residual" and "Pure Error" finely parsing the unexplained variance into components of model fit and randomness, respectively. This granularity aids in identifying the fidelity of the model to the observed data and the inherent variability unexplained by the examined factors.

In essence, this ANOVA table meticulously maps out the impacts of various factors on an experimental outcome, highlighting KOH, Temperature, and Catalyst as the primary influencers, while Ethanol lags behind in significance. This detailed statistical analysis illuminates the pathways through which each factor interplays within the experimental

framework, guiding strategic decisions for resource allocation and adjustments aimed at optimizing outcomes, thereby advancing our comprehension of the underlying data dynamics.

To elucidate the relationship between experimental parameters and the response, regression analysis has been conducted using experimental data. The calculated regression coefficients are provided in Table 7.

Table 7: Calculated regression coefficients.

Term	Coefficient	Standard Error of Coefficient	T-value	P-value
Constant	-65.8	18.0	-3.66	0.001
Temperature	0.457	0.119	3.85	0.001
Ethanol	0.205	0.238	0.86	0.395
KOH	5.935	0.238	24.99	0.000
Catalyst	-95.7	39.6	-2.42	0.022

This regression analysis table meticulously delineates the intricate dynamics between several experimental variables—Temperature, Ethanol, KOH, and Catalyst—and their impact on a specified response, providing a comprehensive quantitative assessment of their roles. Through the precise calculation of regression coefficients, alongside their standard errors, and the statistical rigor of T-values and P-values, the analysis offers a profound understanding of each parameter's statistical weight and its consequent influence on the experimental outcome.

The significant negative coefficient of the constant term underscores the intrinsic baseline of the response, asserting that, even in the absence of variable influences, the response deviates significantly from zero. This finding is pivotal, highlighting the inherent response characteristics before considering the effects of the experimental parameters.

Temperature emerges as a significant modifier of the response, with its positive coefficient revealing a direct proportional relationship. This parameter's statistical significance is validated by both its T-value and P-value, emphasizing its critical role in modulating the response, thereby suggesting a targeted avenue for experimental manipulation to achieve desired outcomes.

In contrast, the role of Ethanol is ambiguous; its coefficient, combined with a high standard error and a T-value that could be considered statistically insignificant, along with a statistically insignificant P-value, indicates that its effect on the response is negligible. This shows that changes in Ethanol concentration will not lead to meaningful changes in the response, thus directing experimental focus away from this parameter.

KOH stands out with its pronounced coefficient, signifying a robust positive correlation with the response. This parameter's overwhelming statistical

significance is incontrovertible, heralding it as a paramount factor in influencing the response. The substantial magnitude of KOH's effect underscores its potential as a primary lever in optimizing experimental outcomes.

The catalyst's coefficient, despite suggesting a possible negative relationship with the response, is enveloped in uncertainty due to its significant standard error and significant P-value. This ambiguity renders the catalyst a less reliable factor for influencing the response, indicating a lower priority in experimental adjustments.

In essence, this rigorous statistical analysis systematically uncovers the differential impact of each experimental parameter on the response, with Temperature and KOH identified as pivotal influencers—offering clear pathways for experimental optimization. Meanwhile, Ethanol and Catalyst, owing to their less pronounced effects, delineate areas where experimental resources might be more judiciously allocated. This nuanced understanding facilitates a strategic approach to experimental design, aiming for enhanced efficiency and targeted outcomes. The regression equation derived from Table 7 is provided in Equation 7:

Conversion% = -65.8 + 0.457·Temperature + 0.205·Ethanol + 5.935·KOH - 95.7·Catalyst (7)

The calculated R^2 (regression coefficient) indicates that the regression equation can explain more than 90% of the variance in the data.

4. CONCLUSION

The efficient management and repurposing of industrial waste stand as pivotal challenges. This study addresses these challenges head-on by transforming Dolomite waste, a byproduct of its high production volumes, into a commercially viable and applicable product. Through a rigorous examination and demonstration of the calcination

process, we've unlocked the potential of waste Dolomite, converting it into a valuable CaO-MgO mixture. This mixture, characterized by its calcination, has found application as a catalyst in subsequent processes, showcasing the innovative repurposing of waste materials.

One of the standout achievements of this research is the depolymerization of waste PET utilizing the catalysts derived from Dolomite waste calcination. This process not only exemplifies a sustainable approach to waste management but also results in the production of TPA, a fundamental raw material in PET manufacturing. Such an outcome not only contributes to the circular economy but also adds value to what would otherwise be considered waste.

Furthermore, the study leverages a systematic experimental design to delve into the hydrolysis of waste PET, meticulously analyzing the influence of individual parameters on the process. This systematic approach enables a deeper understanding of the chemical interactions at play and identifies optimal conditions for maximizing efficiency and output. By integrating waste management with the production of valuable chemical precursors, this research embodies the principles of green chemistry and sustainability, paving the way for innovative solutions in chemical engineering.

In conclusion, the comprehensive analysis presented through the regression model and ANOVA table provides an insightful understanding of the effects of various experimental parameters (Temperature, Ethanol, KOH, and Catalyst) on the conversion process. The derived regression equation, *Conversion% = -65.8 + 0.457·Temperature + 0.205·Ethanol + 5.935·KOH - 95.7·Catalyst*, with an R² value of 94.83, underscores the model's robust ability to explain a significant portion of the variance observed in the conversion rates.

The statistical significance of each parameter, as delineated by the regression analysis, highlights the varying degrees of influence they exert on the conversion outcome. Temperature and KOH emerge as the most impactful factors, with KOH showing a particularly strong positive relationship with conversion, indicating its critical role in the chemical process. On the other hand, Ethanol's influence is minimal, and its parameter's high P-value suggests that changes in ethanol concentration may not substantially affect the conversion rate within the scope of this experimental setup. The Catalyst, despite a suggested negative relationship with the conversion rate, is enveloped in uncertainty due to its considerable standard error and significant P-value, indicating a less deterministic influence on the process.

The significant negative coefficient of the constant term in the regression equation indicates a

meaningful baseline from which the effects of the variables are measured, suggesting that even in the absence of these experimental parameters, the response level is notably different from zero.

Overall, the regression and ANOVA analyses together offer a nuanced view of how each parameter contributes to the conversion process, guiding future experimental designs and optimizations. With KOH identified as the most significant contributor to conversion efficiency, followed by temperature, strategic adjustments in these parameters can be leveraged to optimize conversion outcomes. Meanwhile, the lesser impact of Ethanol and the ambiguous role of the Catalyst provide valuable insights into areas where experimental efforts and resources might be more judiciously applied or conserved.

In the future, the feasibility of conducting studies on the use of catalysts derived from waste materials in the hydrolysis of PET by evaluating the wastes of other ores is observed.

5. CONFLICT OF INTEREST

The authors declare that they have no conflict of interest with anyone in this study.

6. ACKNOWLEDGEMENTS

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