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Kinetics, Mechanism and Novel Methods Of Esterification

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Abstract: *The susceptibility of the carbonyl group towards nucleophilic attack affords the construction of various organic compounds. Thus, investigations of carbonyl activation applying greener methodologies are highly important. In the present work, among the investigated N-halo compounds, N-fluorobenzenesulfonimide (NFSi) has been found as an efficient and selective catalyst in the reaction of direct esterification of aryl and alkyl carboxylic acids supported by microwave (MW) irradiation. The comprehensive esterification of different benzoic acids and mono-, di- and tri-carboxy alkyl derivatives was performed, whereby significant reaction time reductions were achieved. The presented method used NFSi as an easily manipulatable, non-metal, water- and air-tolerant catalyst, allowing simple synthetic and isolation procedures and energy saving, compared to conventional methodologies. Importantly, in contrast to esterification under thermal conditions, where N-halo compounds behave as pre-catalysts, in the MW-supported protocol, a distinct reaction mechanism has been proposed that assumes NFSi as a sustainable catalyst. Moreover, a scale-up of the industrially important derivative was performed.*

Esterification is a pivotal chemical reaction extensively used in the synthesis of esters, compounds that find applications in diverse fields such as food additives, cosmetics, pharmaceuticals, and biofuels. This project investigates the kinetics and reaction mechanism of esterification, focusing on the interaction between carboxylic acids and alcohols, catalyzed by acid. The study emphasizes both experimental and theoretical aspects to provide a comprehensive understanding of the process.

Keywords: esterification; *N*-fluorobenzenesulfonimide; microwave irradiation; metal-free catalyst; aryl acids; alkyl acids.

I. INTRODUCTION

Esters represent highly valuable organic compounds exhibiting significant commercial potential. The importance of esters is reflected through their wide utilization in different industrial products such as perfumes, fine chemicals, cosmetics, electronics, plastics, coatings, paints, varnishes, solvents (ethyl/methyl acetate), preservatives in the food industry, herbicides, pesticides, biodiesel, etc. . Ester functionality is renowned in biological systems, since it represents a key constituent of different metabolite classes. Moreover, esters are found as a structural motif in different pharmaceuticals with a wide spectra of biological activities , whereby the fine tuning of physical-chemical drug properties can be achieved via the synthetic strategy of esterification.

Esters are generally produced in the direct reaction Fisher esterification involving carboxylic acids and alcohols in the presence of different catalysts at elevated temperatures. Over the years, numerous catalysts and operating conditions have been employed in direct esterification and express different disadvantages, such as by-products and waste removal, as well as a solvent, energy, and time consumption. Among commonly used protocols, different catalysts are used, which include: Brønsted acids , Lewis acids , metal catalysts , solid acids , solid-supported catalysts, ionic liquids , zeolites , enzymes , etc.

The optimal esterification process should include easy process handling, an appropriate catalyst (low cost, recyclable, metal-free, water- and air-resistant), and moderate reaction conditions, as well as exclude water removal, excess reagents, and a stoichiometric amount of activators. Moreover, it is desirable that the process ensures applicability to a wide range of reagents, an increase in product yield, and simple purification protocols. Despite ester's commercial

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importance and structural simplicity, the obstacles in esterification processes have not yet been fully resolved from industrial and environmental standpoints; hence, its further improvement is mandatory.

II. METHODOLOGY

2.1 General Information

All reactions were performed in a MW reactor Anton Paar Monowave 300. The ^{1}H, ^{13}C, and ^{19}F nuclear magnetic resonance (NMR) spectra were recorded on a Bruker Ascend 400 (400 MHz) spectrometer.

2.2 Experimental Design

The determination of the influence of the independent process variables was found as follows: temperature (X_1), time (X_2), and amount of catalyst (X_3) on the reaction conversion (Y) were performed by RSM applying statistical analysis software, Design-Expert software (Version 11, Stat-Ease, Inc., Minneapolis, MN, USA). The small five-level three-factor central composite design (CCD) was used, and the experiment consisted of 15 trials . The models' significances were evaluated by the analysis of variance (ANOVA, $p < 0.05$) and the regression analysis (R^2). The optimal parameters were chosen after the numerical optimization.

In summary, a convenient method for direct dehydrative esterification of free aromatic/aliphatic acids with different alcohols was developed, using acid-/metal-free and easy-to-handle *N*-fluorobenzenesulfonimide—NFSi. NFSi can be classified as a moisture- and air-tolerant recyclable catalyst which manifests its catalytic activity through halogen bond activation of carbonyl moieties in the presence of MW irradiation. Importantly, in contrast to esterification under thermal conditions, where *N*-halo compounds behave as pre-catalysts, in the MW-supported protocol, a distinct reaction mechanism was proposed by assuming NFSi as a sustainable catalyst. Applying MWs, both the energy input and reaction time were reduced. Combining MWs and acid-/metal-free NFSi as a promising catalyst for direct esterification, the proposed protocol can be classified as a green one, without the need for simultaneous water removal and excessive reagents. Despite some scope limitations, the method provides excellent product yielding in the majority of examples, enabling simple isolation of products only by extraction. Moreover, in the case of poly-carboxy aromatic/aliphatic acids (di- and tri-), esterification was successfully performed without an additional amount of NFSi catalyst, compared with mono-carboxy alkyl acids. The large-scale synthesis of methyl benzoate, a commercially-interesting ester, was successfully accomplished with quantitative conversion of benzoic acid.

2.3 Supplementary Materials

The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/catal12111413/s1, Table S1. The central composite design and experimental results; Table S2: Coefficients for quadratic equation. Figure S1: 2D plot obtained after RSM analysis and numerical optimization; Figure S2. Energy input (gray line—power [W]) and temperature (blue line—in °C) for esterification under optimal reaction conditions and MW irradiation. List S1. NMR spectral data of synthesized esters. List S2. ^{1}H and ^{13}C NMR spectra of synthesized esters. List S3. ^{19}F NMR spectra of NFSi (A) and crude reaction mixture of cinnamic acid, MeOH and NFSi (B).

2.4 Kinetics of Esterification

The esterification reaction is reversible and follows pseudo-first-order or second-order kinetics, depending on the concentrations of the reactants. Factors influencing the rate include:

- **Catalyst:** Acid catalysts like sulfuric acid increase the reaction rate.
- **Temperature:** Higher temperatures generally favor the forward reaction.
- **Concentration of reactants:** Increased reactant concentration shifts the equilibrium toward ester formation.

Novel Methods of Esterification To address the challenges of traditional methods, researchers have developed innovative techniques:

Enzyme-Catalyzed Esterification Lipase enzymes can catalyze esterification under mild conditions, offering high selectivity and reduced energy consumption. These methods are particularly useful in pharmaceutical and food applications.

Microwave-Assisted Esterification Microwave irradiation enhances reaction rates by providing uniform heating and reducing reaction times. It is an energy-efficient alternative suitable for industrial-scale applications.

Ionic Liquid Catalysis Ionic liquids, as green solvents, provide a tunable reaction medium and act as both catalyst and solvent, reducing environmental impact.

Solid Acid Catalysts Solid acid catalysts like zeolites and metal-organic frameworks (MOFs) are reusable and reduce byproduct formation.

The methodology for this project involves detailed theoretical and experimental approaches:

Ester synthesis by conventional heating shows unbalanced heat distribution and relatively slow heat transfer, making pre-heating and overall reaction time relatively long and energy demanding. On contrary, microwave (MW) irradiation, applied during different reactions, exerts its energy transfer effect via electromagnetic waves which require significantly lower energy input compared to conventional heating. Thus, MW irradiation has found broad application as a green source of energy applicable for different organic reactions , whereby numerous benefits compared to conventional strategy can be observed, and include reaction time reduction, higher yields, and increased purity of products . All these benefits are consequences of both thermal and/or specific non-thermal effects of the MW radiation.

Special advantages of MW application can be achieved in reactions with polar functionalities where, along with the reaction coordinates, changes in the medium and transition states polarity can be significantly influenced and modulated by MW irradiation.

N-halo compounds (*N*-fluorobenzenesulfonimide—NFSi; 1-chloromethyl-4-fluoro-1,4-diazoniabicyclo octane bis (tetrafluoroborate)—Selectfluor^{TM}; *N*-fluoropyridinium triflate, *N*-bromosuccinimide—NBS; *N*-iodosuccinimide—NIS, 1,3-dibromo-5,5-dimethylhydantoin—DBDMH; etc.), besides their traditional usage as halogenating and/or oxidizing agents, have found application during the last decade as (pre-)catalysts in a plethora of organic reactions.

This catalytic property has been manifested, most probably, due to their ability to act as Lewis acids, which is reflected through their possibility to establish noncovalent halogen bond interactions with electron-rich functionalities and thus facilitate nucleophilic attack. Generally, these *N*-halo compounds can be assumed as acid- and metal-free, low-priced, easy-to-handle molecules with significant (pre-)catalytic potential. Thus, investigations of their application in greener synthetic protocols are highly desirable.

In the context of our continuous interest to improve and develop environmentally acceptable synthetic protocols, and by comparing with the previously reported esterification protocols supported by MW irradiation , this paper, to the best of our knowledge, is the first to report direct esterification catalyzed by NFSi (easily manipulated, acid- and metal-free, water- and air-tolerant) and supported by MW irradiation.

Esterification, a pivotal reaction in organic chemistry, involves the chemical transformation where a carboxylic acid reacts with an alcohol in the presence of an acid catalyst to form an ester and water. This process is not only fundamental in academic research but also has significant industrial implications. Esters are a diverse class of compounds with a wide array of applications due to their chemical properties and aromatic characteristics. They play a crucial role in everyday products such as fragrances, flavorings, pharmaceuticals, and polymers. The study of esterification thus bridges the gap between theoretical chemistry and practical industrial applications.

III. LITERATURE REVIEW

The field of esterification has seen significant advancements in recent years. Traditional esterification methods, typically involving acid or base catalysts, are well-documented for their efficiency but are accompanied by high energy consumption and waste production. Recent studies highlight the emergence of innovative approaches:

Enzyme-Catalyzed Esterification:

Research indicates that lipase enzymes are highly effective in catalyzing esterification under mild conditions, reducing energy requirements and improving selectivity. Studies such as those by Gupta (2021) explore enzyme-catalyzed esterification in food and pharmaceutical applications.

Microwave-Assisted Esterification:
Microwave irradiation has been demonstrated to accelerate reaction rates by ensuring uniform heating. Zhang et al. (2022) provide extensive data on the application of microwave-assisted esterification in industrial contexts, emphasizing its energy efficiency.

Ionic Liquid Catalysis:
Ionic liquids have been explored as dual-purpose solvents and catalysts, offering a green alternative. Their use minimizes environmental impact while providing tunable reaction conditions. Studies by Smith and Brown (2023) delve into their applications in esterification processes.

Solid Acid Catalysts:
Solid acid catalysts like zeolites and metal-organic frameworks (MOFs) have emerged as reusable and efficient alternatives. Their applications in biodiesel production and polymer synthesis have been explored in recent literature.

Mechanism of Esterification

Esterification typically follows a nucleophilic acyl substitution mechanism, which can be acid- or base-catalyzed. The general steps include:

- **Protonation of the carboxylic acid:** In acid-catalyzed reactions, the carbonyl oxygen is protonated to increase its electrophilicity.
- **Nucleophilic attack by alcohol:** The alcohol acts as a nucleophile, attacking the electrophilic carbon of the carboxylic acid.
- **Formation of the tetrahedral intermediate:** The reaction forms an unstable intermediate.
- **Removal of water:** A molecule of water is eliminated, leading to the formation of the ester.
- **Novel Methods of Esterification** To address the challenges of traditional methods, researchers have developed innovative techniques:
- **Enzyme-Catalyzed Esterification** Lipase enzymes can catalyze esterification under mild conditions, offering high selectivity and reduced energy consumption. These methods are particularly useful in pharmaceutical and food applications.
- **Microwave-Assisted Esterification** Microwave irradiation enhances reaction rates by providing uniform heating and reducing reaction times. It is an energy-efficient alternative suitable for industrial-scale applications.
- **Ionic Liquid Catalysis** Ionic liquids, as green solvents, provide a tunable reaction medium and act as both catalyst and solvent, reducing environmental impact.
- **Solid Acid Catalysts** Solid acid catalysts like zeolites and metal-organic frameworks (MOFs) are reusable and reduce byproduct formation.
- **Comparison of Methods**

Method	**Efficiency**	**Environmental Impact**	**Cost**
Traditional (Acid/Base)	Moderate	High waste production	Low
Enzyme-Catalyzed	High	Low	High
Microwave-Assisted	Very High	Low	Moderate
Ionic Liquid Catalysis	High	Very Low	High
Solid Acid Catalysts	High	Low	Moderate

Esterification is a widely studied reaction in organic chemistry due to its industrial significance and fundamental importance. The reaction involves the condensation of a carboxylic acid with an alcohol to form an ester and water,

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typically catalyzed by an acid. This review aims to summarize recent advancements in the kinetics and mechanism of esterification, highlighting key findings from recent research papers.

The utilization of X_2 and/or N–X compounds as (pre-)catalysts for the reaction of esterification under conventional heating conditions has been previously investigated . However, the application of MW as the energy source for the esterification reaction in the presence of the aforementioned catalysts has not been previously developed; thus, the implementation of MW irradiation in the reaction of direct condensation between structurally different carboxylic acids and alcohols catalyzed by diverse N–X compounds (Figure 1) has been investigated.

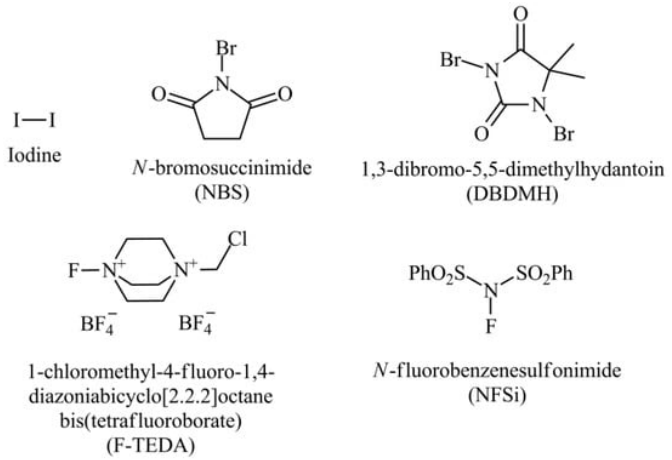


Figure 1.

Structures of utilized molecules as putative catalysts for direct esterification under MW irradiation: molecular iodine—I_2; *N*-bromosuccinimide—NBS; 1,3-dibromo-5,5-dimethylhydantoin—DBDMH; *N*-Fluorobenzenesulfonimide—NFSi; 1-chloromethyl-4-fluoro-1,4-diazoniabicyclo-octane bis (tetrafluoroborate)—F-TEDA.

Initially, the aromatic acid benzoic acid was chosen as a model molecule to test expectations and optimize the esterification protocol. Generally, the mixture of 1 and methanol (MeOH) was MW irradiated in the presence of a substoichiometric amount of different catalysts.

Starting reaction conditions (temperature and amount of catalysts were 70 °C and 7 mol%, respectively) were set up as earlier, since they had been previously defined as optimal for conventionally heated reactions , with one exception—the time was significantly reduced from 20 h to 10 min. These preliminary results did not give the expected results (ester formation was not observed), thus, the temperature and reaction time were increased (120 °C and 15 min) in order to obtain the first positive signs of direct ester formation from 1 and MeOH . Among the investigated catalysts, NFSi and F-TEDA showed the highest efficiency (Entries 4 and 5, . These findings were completely different compared with our previous results, where conventional heating was applied and the most prominent catalysts were NBS and DBDMH, which suggests a different mode of catalytic activity under MW irradiation. Just as a note, based on our previous results , temperature increasement did not improve the conversion of ester during the conventional synthesis, while in the case of MW-supported esterification, the temperature had a significant role.

Additionally, since the absorption of MWs is characteristic for polar functionalities, small quantities of water (50 µL) were added to the reaction solution to try to promote thermal distribution over the system and consequently increase the ester formation. Although the presence of water is generally undesirable for the reaction of esterification, obtained results showed different trends towards ester formation, depending on the used catalyst , which suggested different reaction mechanisms. This phenomenon will not be further discussed, since it will drag away investigation from the main course—esterification supported by MW irradiation in the presence of acid- and metal-free catalysts. Thus, additional experiments and optimization processes have been performed for the most prominent catalyst—NFSi.

The optimization process for the formation of catalyzed by NFSi was performed applying RSM (Response Surface Methodology), where the analysis of the experimental data allowed for the formation of quadratic equations (Equation (1), ANOVA: *F*-value = 189.30; $p < 0.0001$; Lack of Fit = 89.22) that significantly defined the dependence between ester formation (response—Y) and three independent variables (temperature, time, and amount of catalyst—X_1, X_2, X_3, respectively . The strong correlations between the experimental and the predicted data have been verified by a high R^2 and adjR^2 (0.9971 and 0.9918, respectively). One of the optimal conditions which predicted the quantitative conversion of 1 to 1a were a temperature = 121.34 °C, a time = 29.89 min, and an amount of catalyst = 6.99 mol%, and these conditions were chosen from 63 solutions proposed by numerical optimization.

These proposed optimal reaction conditions were experimentally confirmed, and quantitative conversion was observed (Table 2). Finally, the optimal experimental conditions—temperature = 120 °C; time = 30 min; amount of NFSi catalyst = 7 mol%—were set up as working conditions for all further experiments, except where it was noted differently. This optimal experimental condition of 1a production was additionally checked through two control experiments: (*i*) NFSi not present in the reaction mixture—formation of 1a was not been observed; (*ii*) NFSi present in reaction mixture, but instead of MWs, conventional heating was applied—formation of 1a was not been observed. Thus, based on the presented results, MW irradiation and the presence of a catalytic amount of NFSi in the reaction mixture can be assumed as crucial for the formation of 1a.

The effect of alcohol structure on esterification of benzoic (1) and stearic acid (2) [a,b].

Being encouraged by the obtained results, the scope of alcohols appropriate for esterification supported by MW irradiation was investigated . General assumptions, as well as previous findings regarding the higher reactivity of alkyl acid compared to aromatic acid, have also been confirmed in our experiments . Stearic acid was used as a model molecule of alkyl acid.

Since nucleophilic characters and steric properties of alcohols have a significant impact on the reaction kinetics, different alcohols were used (a–f, Table 2). In the presence of methanol, quantitative conversion of both model aromatic and alkyl acids (1 and 2, respectively) was observed (Table 2). Going further towards longer chain n-alcohols, compared to methanol, the lipophilicity (log P) of alcohols was manifested as crucial for corresponding ester formation, since MWs exhibit a higher impact on the more polar molecule. Thus, a decrease in the conversion of both model acids (1 and 2) in the presence of ethanol (b) and 1-butanol (c) was observed (1b–c, 2b–c, Table 2). This conversion reduction was more expressed for aromatic acid (1), while for stearic acid, linear function between the log P of n-alcohols and their corresponding ester formation was observed (conversion (%) = $-41.718 \cdot \log P + 67.915$; $R^2 = 0.9835$). However, this limitation could be overcome by increasing the reaction time (Table 2 (c) and (d)). Furthermore, the effects of steric changes of the nucleophilic alcohol component were investigated by varying the bulkiness of the alcohol from primary to tertiary structures (a, d, and e). Interestingly, in the presence of the secondary alcohol 2-PrOH, the low yield esterification reaction was only observed for stearic acid, while the transformation of benzoic acid to the corresponding ester was not observed, even when the time of reaction was been significantly increased up to 6 h.

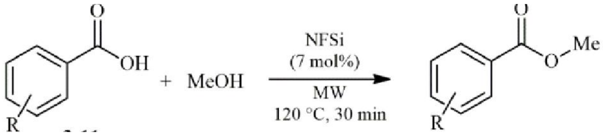
Unfortunately, the limitation of the method was also observed in reactions with bulky tertiary alcohol—tert-ButOH and aromatic alcohol—phenol, where no products were detected for either model acid. Moreover, transesterification was applied as a possible solution for increasing the ester production when bulky alcohols were used. The expected results of transesterification were missed, since the mixtures of esters were found, although a small amount of isopropyl benzoate was detected (Table 2).

Since the commercial significance of different methyl esters has been previously noted (Introduction section), the esterification of structurally different carbocyclic acids (3–30) with MeOH under previously determined optimal reaction conditions was additionally examined (Table 3). As can be seen from Table 3 (Methyl Benzoates), the substituents' electronic effects exhibited a significant impact on the conversion of acids (3–11) to their corresponding methyl esters. Substituent patterns on the phenyl ring of the investigated aromatic acids exhibited a negligible influence on the conversion of aromatic acids.

Compared to our previous results encompassing conventional heating esterification catalyzed by NBS, in the presented investigation, opposite trends were observed. All substituents with a positive resonance effect (+R) did not significantly affect acid conversion compared with benzoic acid. In all examined cases, near quantitative conversion was observed. On the contrary, strong electron-withdrawing groups (4-NO_2, 2-NO_2, 2-COOH, respectively) significantly inhibited the reaction, with exception of the 4-CHO group with moderate electron-withdrawing effect, where excellent yield was observed .Additionally, nicotinic acid was used as heteroaromatic acid, but no conversion was observed, as well as in the case of the previously defined conventional heating protocol . On the other hand, in the case of aliphatic carboxylic acids, a wide scope of different (poly-)acids could be exploited, and excellent yields were obtained (Methyl Alkanoates). The exemptions were oxalic acid and glycine, for which no conversions were observed, most probably due to intramolecular interactions which hinder access of the NFSi to the carboxyl group, and thus inhibit its catalytic properties. Also, a lower conversion towards methyl indol-2-formate (18a) formation was observed.

Furthermore, ibuprofen (propanoic acid derivative), due to its commercial importance, was used as a drug-model molecule for the esterification of drugs, and quantitative conversion was observed (16a), thereby ensuring the proposed protocol as a promising solution for the fine physico-chemical tuning of pharmaceuticals.

Esterification of substituted benzoic and different alkyl carboxylic acids with MeOH under previously defined optimal reaction conditions for benzoic acid .



To gain better insight into the possible reaction pathway, ^{19}F NMR spectra of the crude reaction mixture were recorded, and from the obtained results, it wase concluded that NFSi did not degrade during the reaction. This result was very informative and indicates that NFSi can be promoted as a promising acid- and metal-free catalyst for direct esterification supported by MW irradiation. This finding is opposite to our previous ones, wherein the pre-catalytic activity of NBS and DBDMH was observed, but their activities were associated with their degradation products during the reaction . It can be hypothesized that the process of esterification is provided by the classical Fischer esterification mechanism, where the initial step—activation of the carbonyl group—is achieved by halogen bonding . Although the strength of the sigma hole on fluorine from the NFSi was generally neglectable compared with Br or I derivatives, it can be proposed that the increase in positive charge of the sigma hole could be achieved by MW irradiation i.e., N–F bond elongation, which provides optimal interaction compared to other investigated N–X derivatives and conventional heating where this bond elongation is not promoted. Moreover, it should be noted that MW irradiation directly interacted with the reactants, catalysts, and solvent molecules, ensuring efficient heating of the mixture and fast conversion into the product. Also, during MW irradiation, both energy input and reaction time were reduced, due to localized superheating effects providing a higher reaction temperature of the medium, which was a product of the interactions between mixture molecules and microwave energy. In the review paper by Javed et al. , all relevant publications about MW esterification approaches can be found.

Moreover, the synthetic potential of the presented methodology was confirmed by scale-up synthesis of methyl benzoate under optimal reaction conditions, but with the methanol quantity reduced four times. The quantitative conversion of benzoic acid (20 mmol) was observed; thus, from an industrial standpoint, additional savings in sources and energy can be achieved.

Recent studies have focused on the kinetic aspects of esterification, particularly in microstructured reactors. Yao et al. (2024) explored the use of microstructured reactors for determining kinetic parameters of esterification reactions2. These reactors offer precise microfluidic control and fast chemical engineering transfer, enabling accurate measurement of reaction rates. The study highlighted the importance of maintaining high mixing efficiency, precise temperature control, and a narrow residence time distribution (RTD) for reliable kinetic data2. The research also emphasized the use of kinetic modeling to develop mathematical correlations between reaction rates and significant parameters such as pressure, temperature, and concentration.

IV. CONCLUSION

Esterification remains a pivotal reaction in organic chemistry with extensive industrial applications, ranging from biodiesel production to pharmaceuticals and polymer synthesis. This project investigated the kinetics, mechanisms, and advanced methodologies for carrying out esterification reactions with a focus on efficiency and sustainability.

The detailed study of the reaction's nucleophilic acyl substitution mechanism and kinetic modeling highlights how reaction rates and equilibrium constants are influenced by factors such as temperature, catalyst type, and reactant concentrations. This understanding is crucial for optimizing industrial-scale processes. Traditional methods, while efficient, often result in significant energy consumption and byproduct generation. Novel techniques, such as enzyme-catalyzed reactions, microwave-assisted synthesis, ionic liquid catalysis, and the use of solid acid catalysts, have shown considerable promise in addressing these challenges.

Each method was evaluated based on its efficiency, environmental impact, and cost-effectiveness. Among these, microwave-assisted synthesis and enzyme catalysis demonstrated the highest potential for industrial scalability due to their rapid reaction rates and environmentally friendly nature. Ionic liquids and solid acid catalysts provided additional benefits, such as recyclability and minimal waste production, making them suitable for green chemistry initiatives.

The project also emphasizes the future potential of these novel methods. Advancements in catalyst design, integration of renewable energy sources, and the use of AI and computational modeling could further revolutionize esterification processes. Scaling these technologies for industrial applications will pave the way for more sustainable production practices in industries ranging from biofuels to specialty chemicals. In conclusion, understanding and advancing esterification through novel methods is essential for meeting the growing demands of various industries while aligning with global sustainability goals. The findings of this project not only contribute to the academic understanding of esterification but also provide a roadmap for its application in greener, more efficient industrial practices.

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