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Saja Ahmed Niyazi
 Department of Chemistry,
 College of Science, University
 of Kirkuk, Kirkuk, Iraq

Nooraldeen Ibrahim Abdulla
 Department of Chemistry,
 College of Science, University
 of Kirkuk, Kirkuk, Iraq

Synthesis, characterization, and kinetic analysis of the thermal rearrangement mechanism of tertiary amine oxides

Saja Ahmed Niyazi and Nooraldeen Ibrahim Abdulla

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Abstract

The study explores the synthesis of aromatic tertiary amines (S1-S3), which were prepared by reacting substituted piperidine derivatives with benzene derivatives under reflux conditions. The resulting primary amines were subsequently oxidized using 30% hydrogen peroxide, leading to the formation of N-oxide derivatives (S4-S6). These tertiary amine N-oxide compounds then underwent thermal rearrangement under reflux in dioxane, yielding the corresponding derivatives (S7-S9). Kinetic studies of the thermal rearrangement were also conducted to examine the reaction mechanism and rate. The synthesized compounds were characterized using a range of analytical techniques, including Proton Nuclear Magnetic Resonance ($^1\text{H-NMR}$), Carbon-13 Nuclear Magnetic Resonance ($^{13}\text{C-NMR}$), Fourier Transform Infrared (FT-IR) spectroscopy, and Ultraviolet (UV) spectroscopy.

Keywords: Piperidine, N-oxide derivatives, thermal rearrangement, kinetic studies

Introduction

Tertiary amine oxides, characterized by the general formula $\text{R}_3\text{N}^+\text{O}^-$, where R represents organic groups (typically alkyl or aryl) attached to a nitrogen atom (Figure 1), The first report of an amine N-oxide was due to Pinner and Wolffenstein, and dates back to the end of the 19th century ^[1].

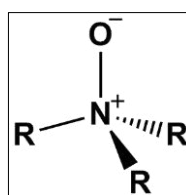


Fig 1: The structure of tertiary amine oxide

Their unique chemical configuration, characterized by a positively charged nitrogen atom and an oxygen atom possessing a lone pair of electrons, constitutes a distinctive category of compounds which endows them with a diverse array of chemical and physical characteristics that render them indispensable in both industrial and biological contexts. Within industrial applications, tertiary amine oxides are extensively utilized as surfactants within detergent formulations ^[2-6], where they effectively reduce surface tension, augment cleaning efficiency, and stabilize emulsions. Their capability to act as proficient fabric softeners further underscores their significance in textile manufacturing, enhancing the texture and durability of fabrics while enabling high-performance finishes ^[7,8]. Moreover, they function as catalysts in various industrial processes ^[9]. Additionally, their prospective contributions to environmental sustainability are currently being investigated, particularly in the realm of wastewater treatment ^[10-12], wherein they facilitate the elimination of pollutants, including oils and organic contaminants. From a biological perspective, tertiary amine oxides demonstrate pronounced antimicrobial properties ^[13], compromising bacterial and fungal cell

Corresponding Author:
Saja Ahmed Niyazi
 Department of Chemistry,
 College of Science, University
 of Kirkuk, Kirkuk, Iraq

membranes, which renders them valuable in the formulation of disinfectants and antiseptics. They are also the subject of research for potential application in drug delivery systems [14], as their amphiphilic characteristics enable interaction with biological membranes, thereby promoting the controlled release of therapeutic agents. Their membrane-active properties have prompted investigations into their utility for treating neurodegenerative disorders, such as Alzheimer's disease [15], as well as for enhancing the efficacy of cancer therapies [16]. This paper is concerned with the preparation and rearrangement of some selected N-arylpiperidine N-oxides.

Materials and Methods

All reagents employed in this study were sourced from Aldrich, Fluka, and BDH and were used as received without any further purification. ¹H-NMR and ¹³C- NMR spectra were recorded on a Bruker AVANCE NEW-400, 400 MHz high-performance digital NMR spectrometer. FT-IR spectra

were acquired using KBr discs on a SHIMADZU FT-IR spectrometer. UV-Vis spectra were measured with a T92+ double-beam spectrophotometer, using a 1.0 mm quartz cell. The melting points of the compounds were determined with a Stuart SMP30 melting point apparatus.

Procedure

General synthesis of aromatic tertiary amines S(1-3)

All novel aromatic tertiary amines S(1-3) were synthesized through the reaction of benzene derivatives (0.094 mol) with piperidine derivatives (0.282 mol) in the presence of 30 mL of dimethyl sulfoxide (DMSO). The reaction mixture was stirred and refluxed for 2 h at 60 °C. After completion, the mixture was allowed to cool, then filtered. The filtrate was washed with water and dried. The resulting precipitate was subsequently recrystallized from ethanol. The physical properties of synthesis aromatic tertiary amines are shown in Table 1.

Table 1: The physical properties of synthesis aromatic tertiary amines S(1-3).

Compound	A	B	Molecular formula	Melting point, °C	Color	Yield %
S1	2-CH ₃	H	C ₁₂ H ₁₆ O ₂ N ₂	137-139	yellow	78
S2	4-CH ₃	NO ₂	C ₁₂ H ₁₅ O ₄ N ₃	83-86	orange	89
S3	3-CH ₃	H	C ₁₂ H ₁₆ O ₂ N ₂	132-135	Orange	97

General synthesis of tertiary amines oxide S(4-6)

The dropwise addition of hydrogen peroxide (H₂O₂, 17 mL) to a solution of aromatic tertiary amine derivatives (0.025 mol) in absolute ethanol was carried out with continuous stirring. The mixture was then heated to reflux. After 4 hours, the reaction mixture was allowed to cool, and the

excess H₂O₂ was decomposed using manganese dioxide (MnO₂). The mixture was then filtered to remove the MnO₂, and the filtrate was dissolved in diethyl ether, washed with water, and dried, yielding the tertiary amine oxide derivatives. The physical properties of synthesis aromatic tertiary amine oxides are shown in Table 2.

Table 2: The physical properties of synthesis aromatic tertiary amine oxides s(5-8).

Compound	A	B	Molecular formula	Melting point °C	Color	Yield %
S5	2-CH ₃	H	C ₁₂ H ₁₆ O ₂ N ₂	122-123	Red	80
S7	4-CH ₃	NO ₂	C ₁₂ H ₁₅ O ₄ N ₃	Oil	Yellow	95
S8	3-CH ₃	H	C ₁₂ H ₁₆ O ₂ N ₂	119-121	Red	90

Thermal rearrangement of tertiary amine oxides S(7-9)

Heat 1.0 g of amine oxide derivatives in anhydrous dioxane with gradual heating and stirring over a specified duration. After heating, allow the mixture to cool and remove the solvent (dioxane) under reduced pressure. The mixture was then poured into a neutral alumina column under controlled

pressure. The resulting compounds were eluted using a mixture of chloroform and petroleum ether. The solvent was then evaporated. The final product obtained is solid or semi-solid. The physical properties of synthesis Rearrangement of the N-Oxides are shown in Table 3.

Table 3: The physical properties of synthesis rearrangement of the N-oxides S(7-9).

Compound	A	B	Molecular Formula	Melting point, °C	Color	Yield%
S7	2-CH ₃	H	C ₁₂ H ₁₆ O ₃ N ₂	96-98	Brown	95
S8	4-CH ₃	NO ₂	C ₁₂ H ₁₅ O ₅ N ₃	Oil	Yellow	69
S9	3-CH ₃	H	C ₁₂ H ₁₆ O ₃ N ₂	91-93	Red	68

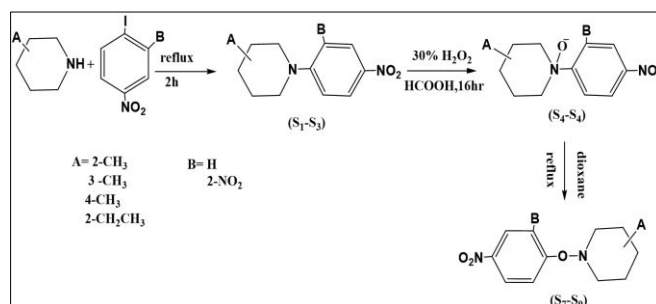
Results and Discussion

The synthesis of tertiary amine oxides was executed through a tripartite reaction sequence. In the P; OL Tertiary aromatic amines. This reaction was conducted in an appropriate organic solvent under meticulously regulated temperature conditions, thereby ensuring adequate mixing to attain a high yield of the desired tertiary amine derivatives. Upon completion of the reaction, the resulting mixture underwent purification via conventional separation and purification methodologies, aimed at isolating the tertiary aromatic amines. In the subsequent phase, the isolated secondary amine derivatives were subjected to oxidation

processes to produce tertiary amine oxides, utilizing hydrogen peroxide as the oxidizing agent. The reaction was carried out under mild conditions to avert over-oxidation or degradation of the resultant product. In the final phase, a kinetic investigation of the rearrangement of the tertiary amine oxides was undertaken to elucidate the factors impacting their stability and reactivity. The rearrangement was monitored under a variety of conditions, including variations in temperature and solvent composition, to ascertain the activation energy and reaction kinetics. The data amassed during this investigation facilitated the optimization of the reaction conditions to ensure maximal

stability of the tertiary amine oxides, thereby providing profound insights into their behavior under diverse environmental conditions. All resultant compounds were subsequently purified, dried, and characterized utilizing

spectroscopic techniques (such as NMR, IR, and UV) to validate their chemical structure and purity. All synthesized compounds are presented in Scheme 1.



Scheme 1: Synthesis of tertiary amine, tertiary amine oxide, and thermal rearrangement of tertiary amine oxide derivatives

Characterization of aromatic tertiary amines S(1-3)

The analysis demonstrated distinct physical characteristics in the synthesized compounds compared to the starting materials, as revealed by infrared spectroscopy. The spectra indicated various functional group vibrations, including

those related to, aromatic C-H stretching, aliphatic C-H stretching, and aromatic C=C vibrations^[17-19]. Additional peaks were observed for C-N stretching, as detailed in as detailed in Table 4 and Figures 2 and 3.

Table 4: The FT-IR data of compounds (S1-S3).

FT-IR, (KBr), cm ⁻¹				
S. No.	$\nu(\text{=CH})\text{Ar}$	$\nu(\text{C-H})/\text{Aliph}$	$\nu\text{C=CAr}$	$\nu\text{C-N}$
S1	3104	2966	1557	1241
S2	3031	2958	1604	1236
S3	3079	2884	1537	1259

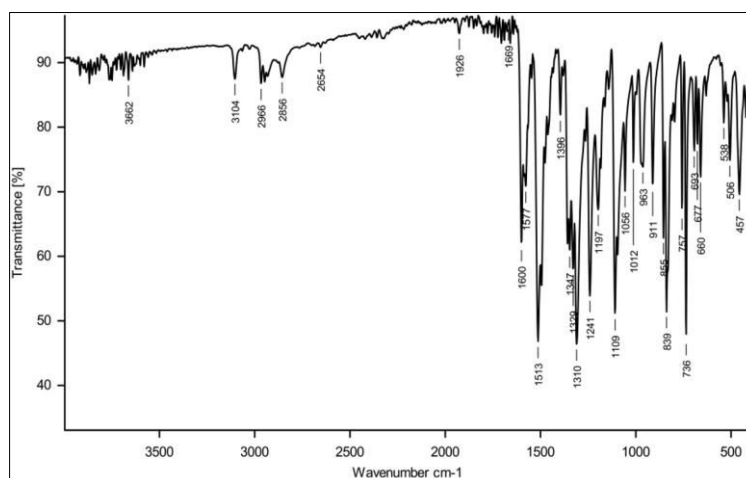


Fig 2: The FT-IR spectrum of compound S1.

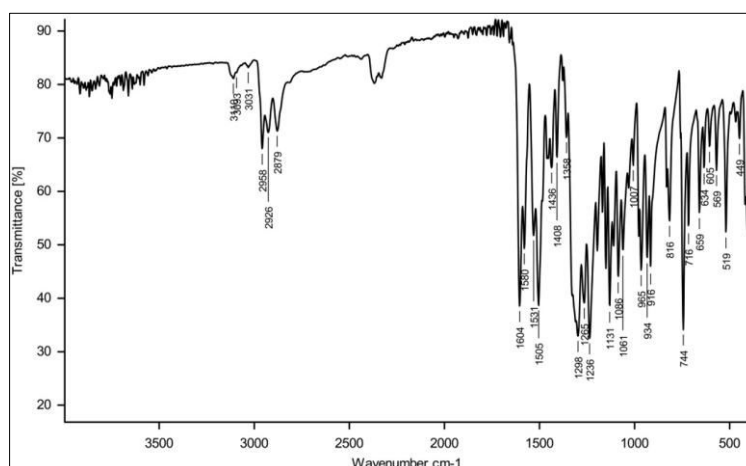
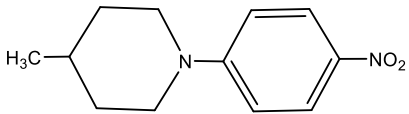
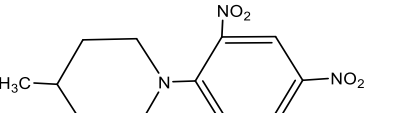
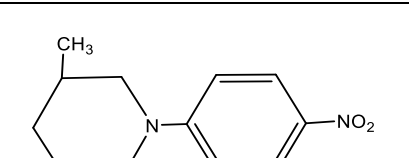


Fig 3: The FT-IR spectrum of compound S3.

The ^1H -NMR spectrum of compounds was obtained using dimethyl sulfoxide as the solvent with deuterium lock. The

^1H -NMR spectral data of tertiary amines are shown in Table 5 and Figure 4 and 5.

Table 5: The ^1H -NMR data of compounds (S1-S3).

Compound	Structures	^1H NMR Spectral data (δ ppm)
S1		1.108-1.226 (d, 3H, CH_3) 1.617-1.753 (q, 2H, CH_2) 2.652-2.835 (m, 1H, CH) 3.757-3.837 (t, 2H, CH_2) 3.757-3.837 (t, 2H, CH_2) 8.205-8.563 (d, 4H, CH arom)
S2		1.268-1.276 (d, 3H, CH_3) 1.627-1.663 (q, 2H, CH_2) 3.372-3.567 (m, 1H, CH) 3.783-3.837 (t, 2H, CH_2) 7.369-8.557 (s,dd, 3H, CH arom),
S3		1.127-1.164 (d, 3H, CH_3) 1.568-1.594 (quintet, 2H, CH_2) 2.592-2.651 (q, 2H, CH_2) 2.880-2.886 (m, 1H, CH) 3.211-3.317 (d, 2H, CH_2) 3.421-3.437 (t, 2H, CH_2) 7.160-7.516 (d, 4H, CH arom).

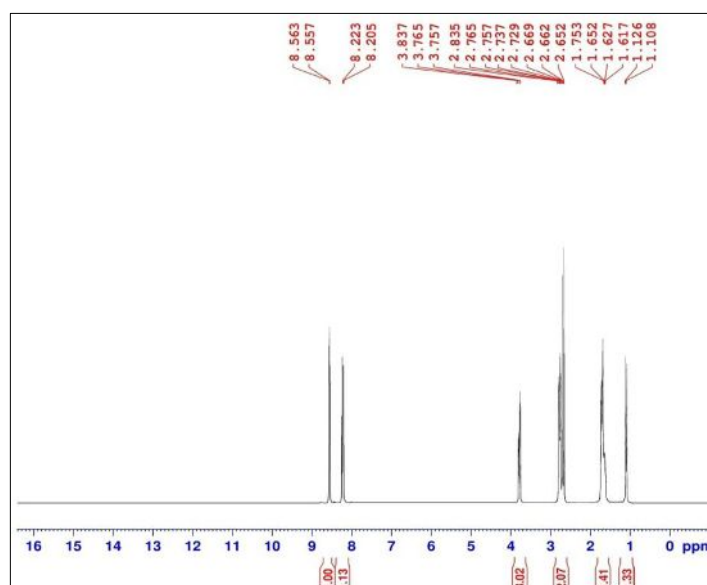


Fig 4: The ^1H -NMR spectrum of compound S1.

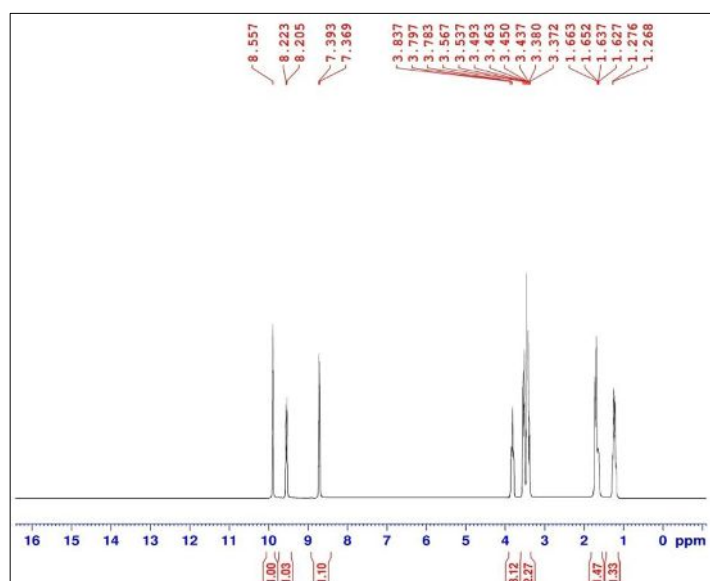


Fig 5: The ^1H -NMR spectrum of compound S3.

The ^{13}C -NMR spectrum of compounds was obtained using dimethyl sulfoxide as the solvent with

deuterium lock. The ^1H -NMR spectral data of tertiary amine oxides are shown in Table 6 and Figure 6 and 7.

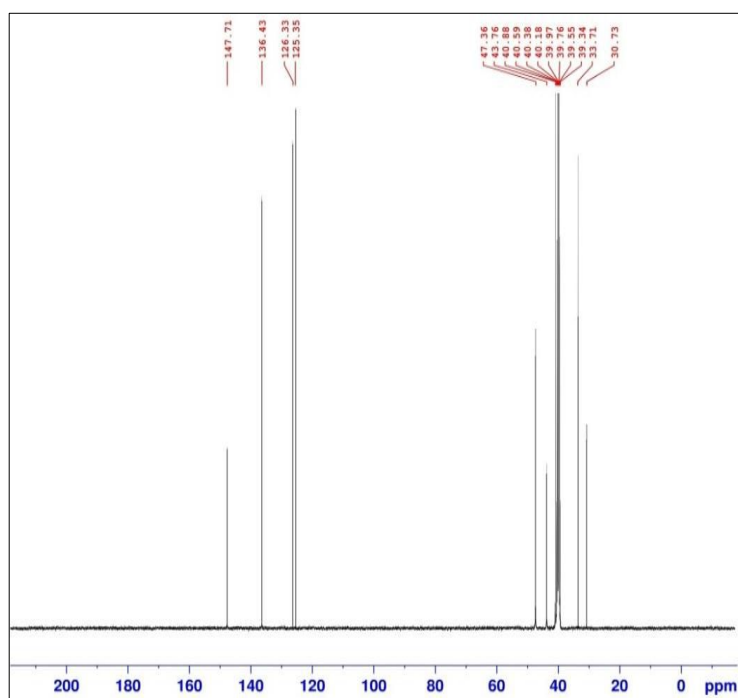


Fig 6: The ^{13}C -NMR spectrum of compound S1.

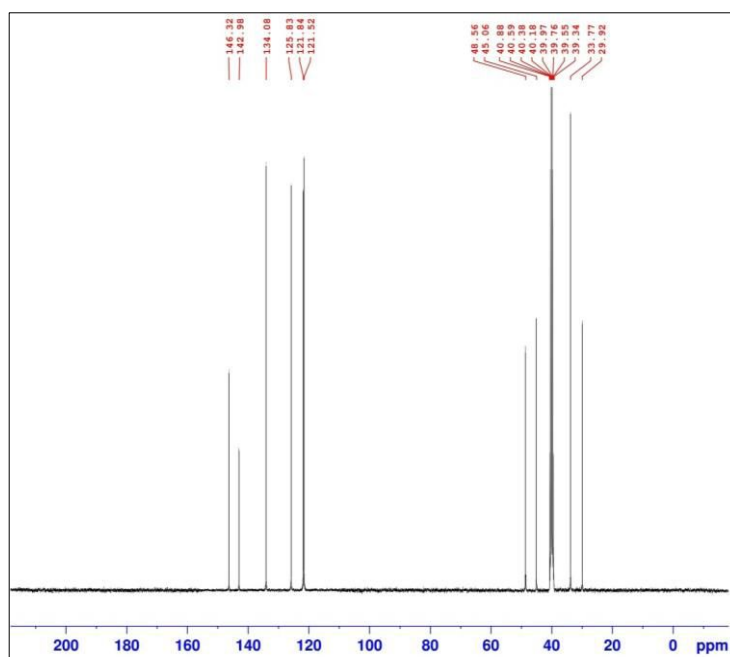


Fig 7: The ^{13}C -NMR spectrum of compound S2.

Table 6: ^{13}C -NMR data of compounds (S1-S3).

Compound	^{13}C -NMR Spectral data (δ ppm)
S1	125.35, 126.33, 136.43 and 147.71(C_{arom}), 47.36, 43.76, 33.71, 30.73.
S2	121.52, 121.84, 125.83, 134.08, 142.98 and 146.32 (C_{arom}), 48.56, 45.06, 33.77, 29.92.
S3	125.77, 126.68, 130.31 and 136.29 (C_{arom}), 54.47, 47.52, 32.90, 30.55, 24.78, 22.31.

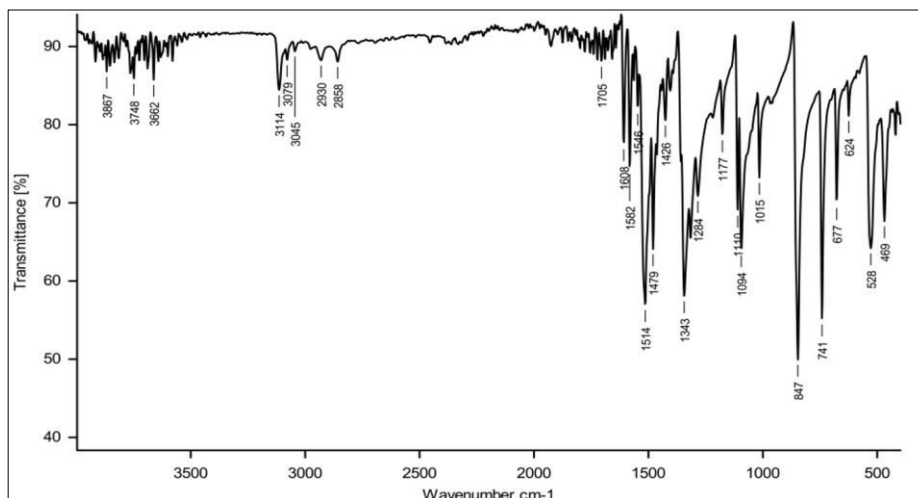
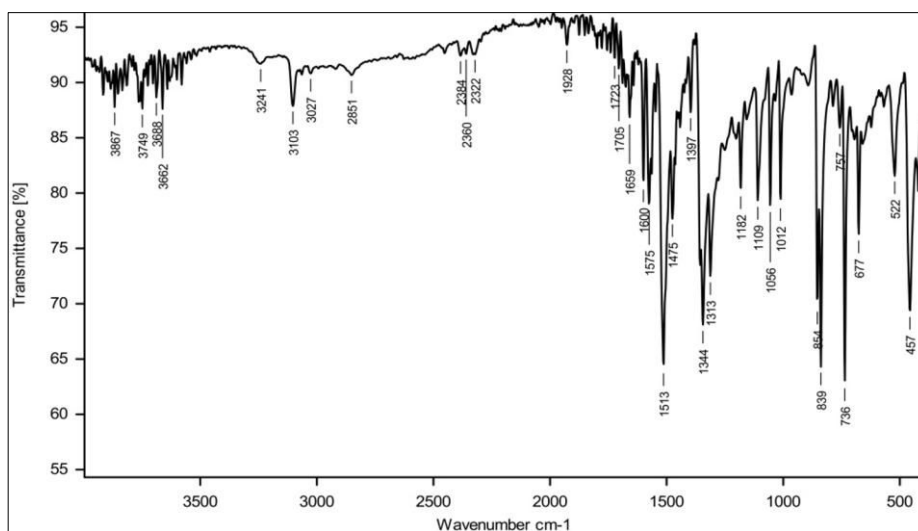
Characterization of tertiary amines oxide (S4-S6)

The analysis demonstrated distinct physical characteristics in the synthesized compounds compared to the starting materials, as revealed by infrared spectroscopy. The spectra indicated various functional group vibrations, including

those related to aromatic C-H stretching, aliphatic C-H stretching, and aromatic C=C vibrations. Additional peaks were observed for C-N and, as detailed in Table 7 and illustrated in Figures 8 and 9.

Table 7: The FT-IR data of compounds (S4-S6).

No.	FT-IR, (KBr), cm^{-1}			
	$\nu(\text{=CH})\text{Ar}$	$\nu(\text{C-H})/\text{Aliph}$	$\nu\text{C=CAr}$	$\nu\text{C-N}$
S4	3079	2930	1608	1284
S5	3103	2851	1575	1313
S6	3012	2914	1597	1252

**Fig 8:** The FT-IR spectrum of compound S4.**Fig 9:** The FT-IR spectrum of compound S5.

The ^1H -NMR spectral data tertiary amine oxides are shown in Table 8 and Figures 10 and 11

Table 8: The ^1H -NMR spectrum of compound (S4-S6).

Compound	Structures	^1H NMR Spectral data (δ ppm)
S4		1.242-1.294 (d, 3H, CH_3), 2.459-2.542 (q, 2H, CH_2), 2.901-3.137(m, 1H, CH), 3.895-3.974 (t, 2H, CH_2), 7.709 -8.203 (d, 4H, CH_{arom})
S5		1. 312-1.361 (t, 3H, CH_3). 2.095-2.152 (q, 2H, CH_2), 3.440-3.550 (m, 1H, CH), 4.355-4.405 (t, 2H, CH_2), 7.376 -8.550 (s, dd, 3H, CH_{arom})
S6		1.135-1.152 (d, 3H, CH_3), 1.874-1.914 (quintet, 2H, CH_2), 2.598-2.674 (q, 2H, CH_2), 2.885-2.902 (m, 1H, CH) 3.321-3.332 (t, 2H, CH_2), 3.432-3.447 (d, 2H, CH_2), 7.175-7.534 (d, 4H, CH_{arom}),

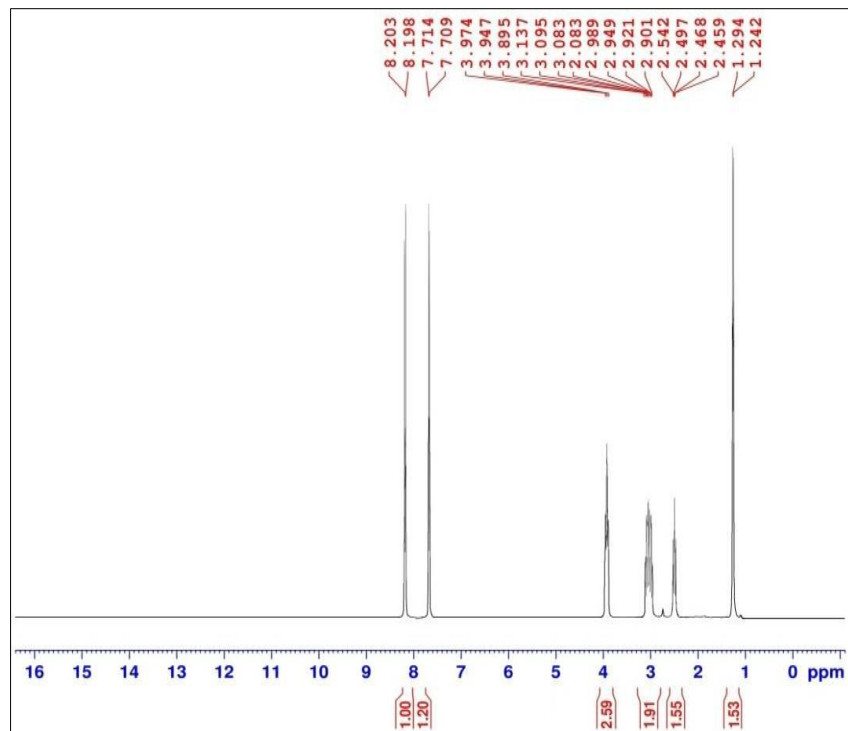


Fig 10: The ^1H -NMR spectrum of compound S4

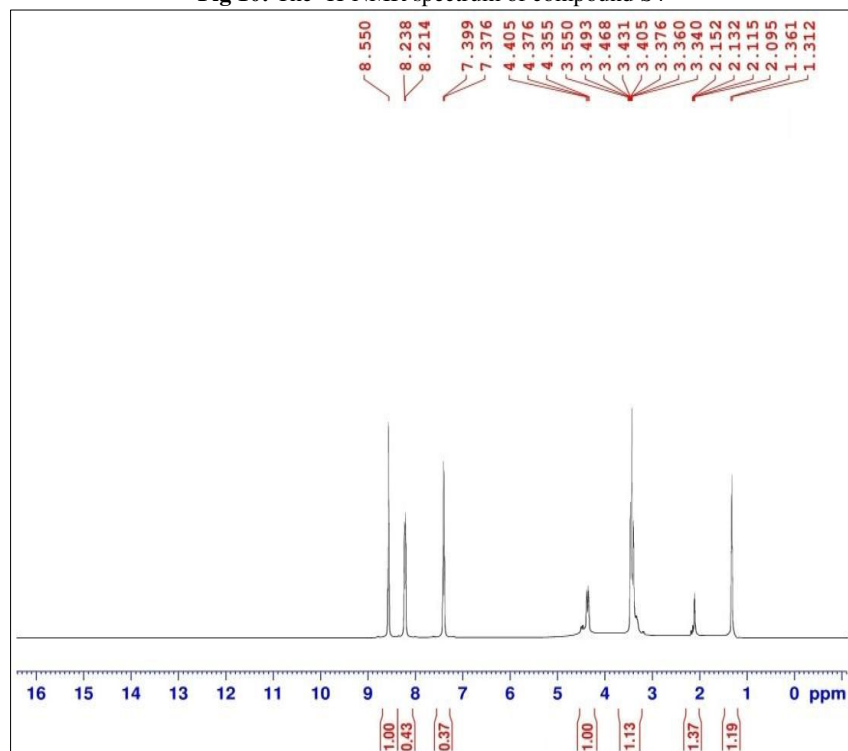


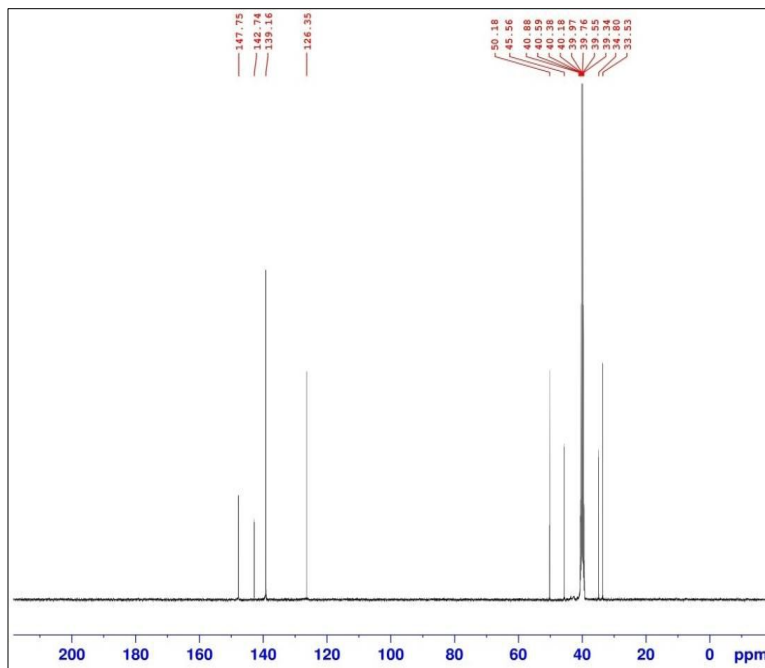
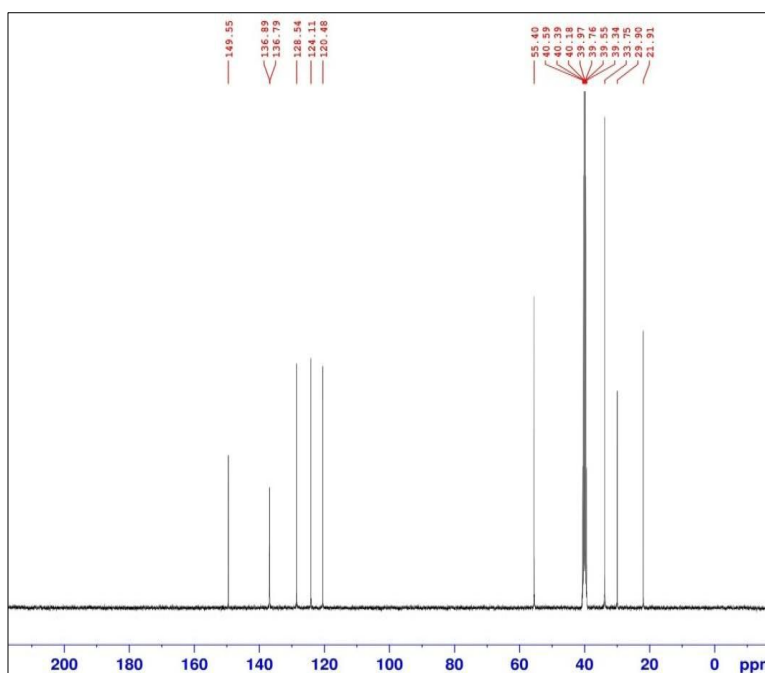
Fig 11: The ^1H -NMR spectrum of compound S5.

The ^{13}C -NMR spectrum of compounds was obtained using dimethyl sulfoxide as the solvent with

deuterium lock. The ^1H -NMR spectral data of tertiary amine oxides are shown in Table 9 and Figure 12 and 13.

Table 9: The ^{13}C -NMR data of compounds (S4-S6).

Compound	^{13}C -NMR Spectral data (δ ppm)
S4	126.35, 139.16, 142.74 and 147.75 (C_{arom}), 50.18, 45.56, 34.80, 33.53
S5	(120.48, 124.11, 128.54, 136.79, 136.89 and 149.55 (C_{arom}), 55.40, 33.75, 29.90, 21.91.
S6	125.77, 126.68, 130.31 and 137.62 (C_{arom}), 54.47, 47.52, 32.90, 30.55, 24.78, 22.3147.

Fig 12: The ^{13}C -NMR spectrum of compound S4Fig 13: The ^{13}C -NMR spectrum of compound S5.

Characterization of thermal rearrangement of tertiary amine oxides (S7-S9)

The analysis demonstrated distinct physical characteristics in the synthesized compounds compared to the starting materials, as revealed by infrared spectroscopy. The spectra

indicated various functional group vibrations, including those related to aromatic C-H stretching, aliphatic C-H stretching, and aromatic C=C vibrations. Additional peaks were observed for C-N and, as detailed in Table 10 and illustrated in Figures 14 and 15.

Table 10: The FT-IR data of compounds (S7-S9).

No.	FT-IR , (KBr), cm^{-1} Fixed bands in structure				
	$\nu(\text{=CH})$ Ar	$\nu(\text{C-H})$ (Aliph	$\nu\text{C=CAr}$	$\nu\text{C-O}$	$\nu\text{C-N}$
S7	3101	2939	1599	1512	1249
S8	3022	2976	1604	1518	1265
S9	3046	2991	1607	1515	1284

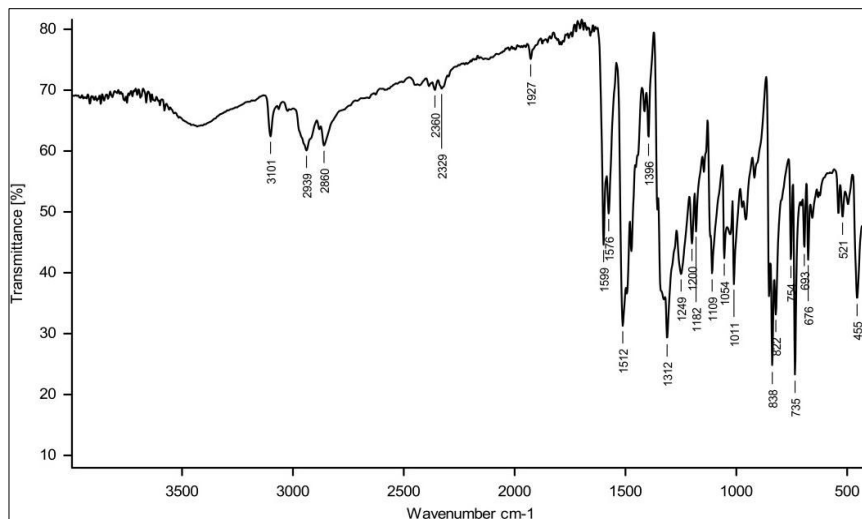


Fig 14: The FT-IR spectrum of compound S7.

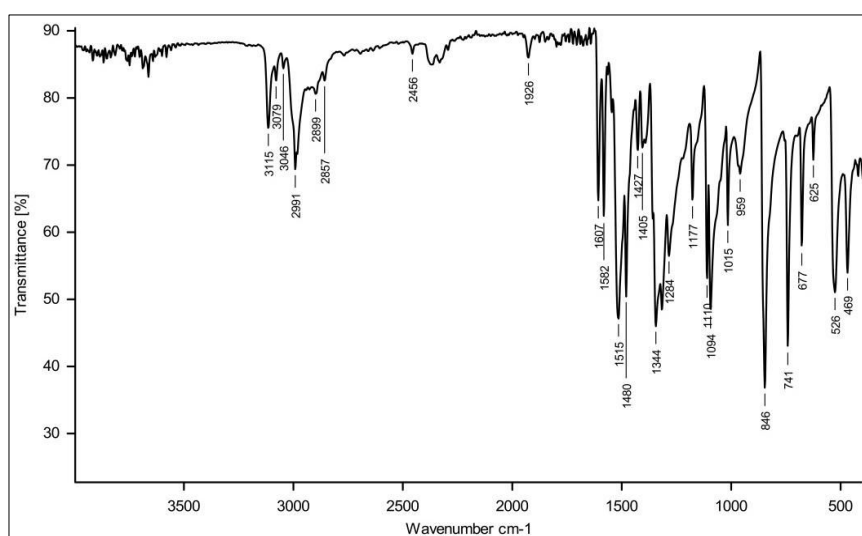


Fig 15: The FT-IR spectrum of compound S9.

The ^1H -NMR spectral data tertiary amine oxides are shown in Table 11 and Figures 16 and 17

Table 11: ^1H NMR data of compounds (S7-S9).

Compound	Structures	^1H NMR Spectral data (δ ppm)
S7		1.116-1.176 (d, 3H, CH_3), 1.855-1.936 (q, 2H, CH_2), 2.427-2.547 (m, 1H, CH), 4.152-4.197 (t, 2H, CH_2), 8.205-8.563 (d, 4H CH_{arom})
S8		1.715-1.739 (d, 3H, CH_3), 2.467-3.214 (q, 2H, CH_2), 3.841-3.895 (m, 1H, CH), 4.121-4.198 (q, 2H, CH_2), 7.879-8.576 (d, 3H, CH_{arom})
S9		1.049-1.091 (d, 3H, CH_3), 1.1844-1.913 (q, 2H, CH_2), 1.963-2.048 (quintet, 2H, CH_2), 3.344-3.496 (m, 1H, CH), 4.154-4.204 (t, 2H, CH_2), 4.948-4.994 (t, 2H, CH_2), 8.548-8.779 (d, 4H, CH_{arom})

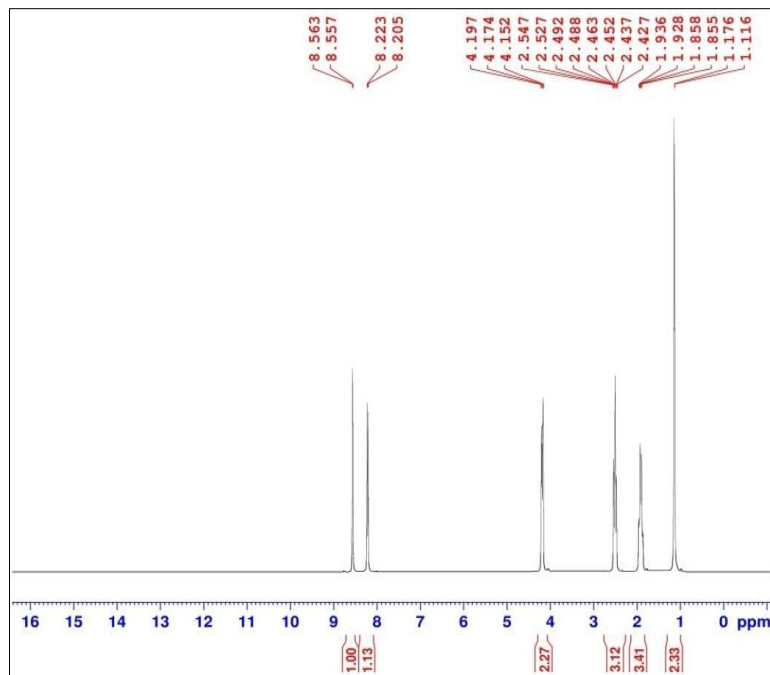


Fig 16: The ^1H -NMR spectrum of compound S7

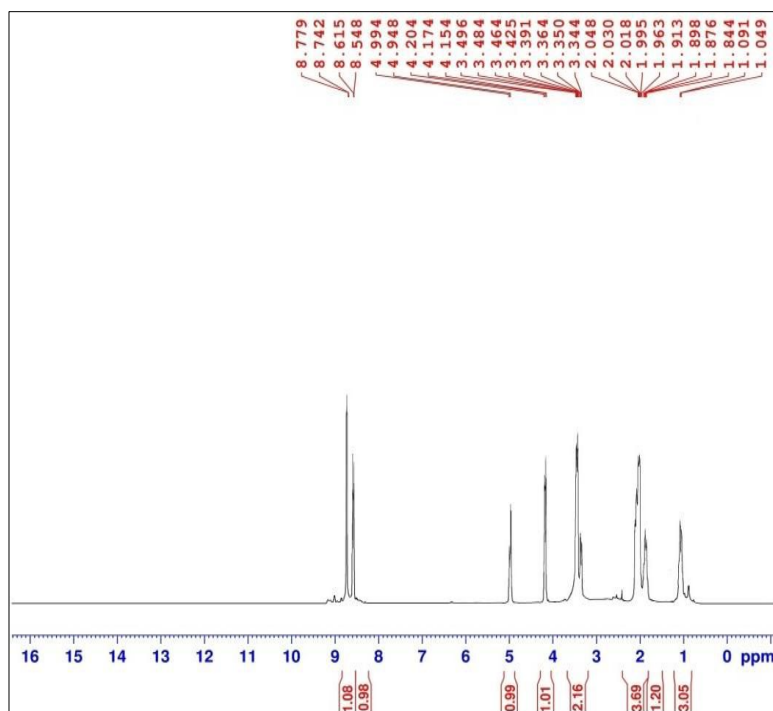
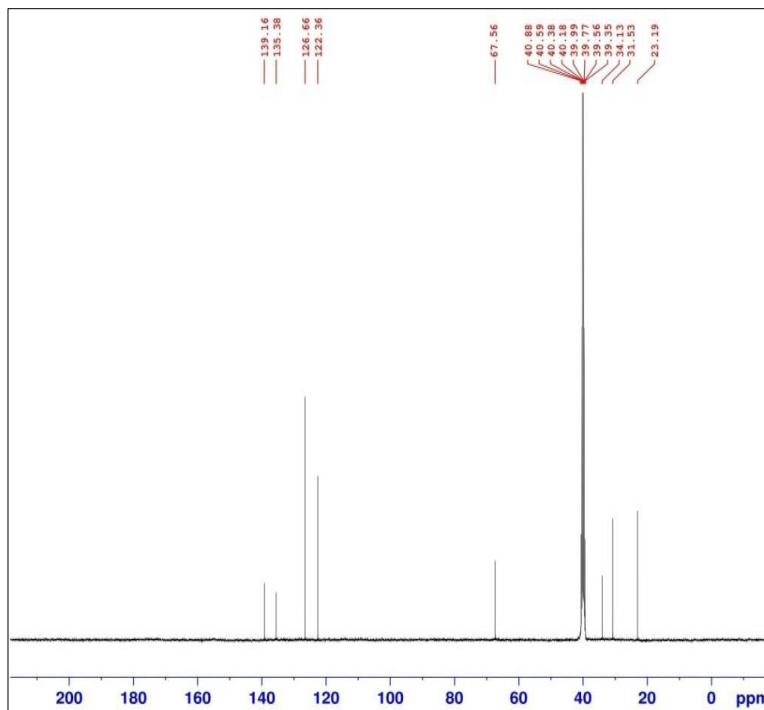
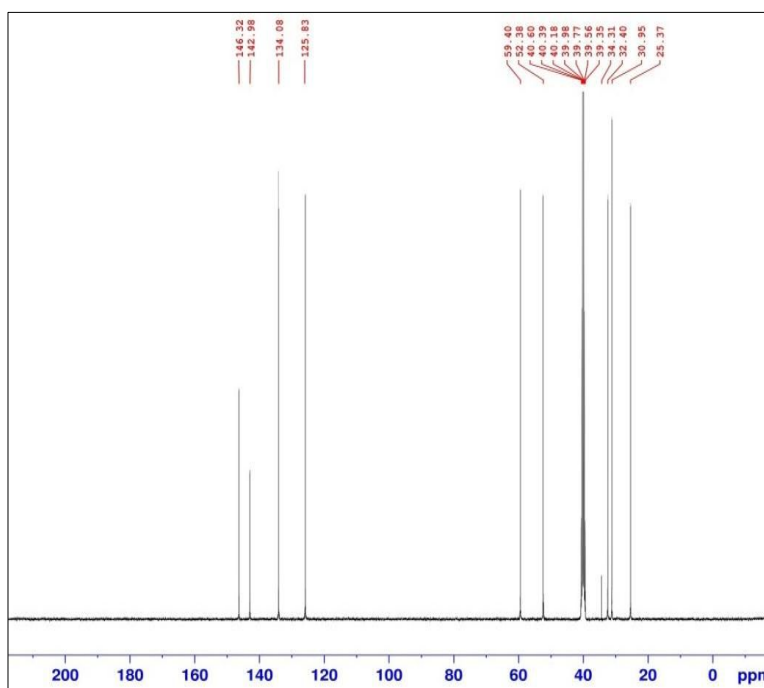


Fig 17: The ^1H -NMR spectrum of compound S9.

The ^{13}C -NMR spectrum spectrum of compounds was obtained using dimethyl sulfoxide as the solvent with deuterium lock.
The ^1H -NMR spectral data of tertiary amine oxides are shown in Table 12 and Figures 18 and 19.

Fig 18: The ^{13}C -NMR spectrum of compound S7Fig 19: The ^{13}C -NMR spectrum of compound S9Table 12: ^{13}C -NMR data of compounds (S7-S9).

Compound	^{13}C -NMR spectral data (δ ppm)
S7	122.36, 126.66, 135.38 and 139.26 (C_{arom}), 67.56, 34.13, 31.53, 23.19.
S8	(122.33, 124.23, 124.62, 127.22, 138.91 and 148.03 (C_{arom}), 53.12, 44.62, 34.33, 29.98.
S9	125.83, 134.08, 142.98, and 146.32 (C_{arom}), 59.40, 52.38, 34.31, 32.40, 30.95, 25.37

Kinetic Measurements

Determine the reaction order

Reaction rates were determined spectrophotometrically by monitoring the absorbance at the λ_{max} of the rearrangement product as a function of time. The experiments were performed in duplicate, with each run reaching 75-85% completion. A stock solution was prepared by dissolving 0.008-0.01 g of freshly synthesized amine N-oxide in 10 mL

of anhydrous dioxane. A 0.2-0.4 mL aliquot of this solution was then diluted with thermostated dry dioxane. Absorbance measurements were initiated immediately after dilution. The "infinity" absorbance (A_{∞}) for each reaction was determined experimentally by allowing the amine oxide solution to equilibrate at the desired temperature until no further change in absorbance was observed. The reaction rate constants were calculated from the slope of the plot of

$\ln(A_{\infty} - A_t)$ versus time. The data presented in Figures 20-22 demonstrate that the thermal rearrangement of the tertiary

amine oxide follows first-order kinetics for all compounds investigated.

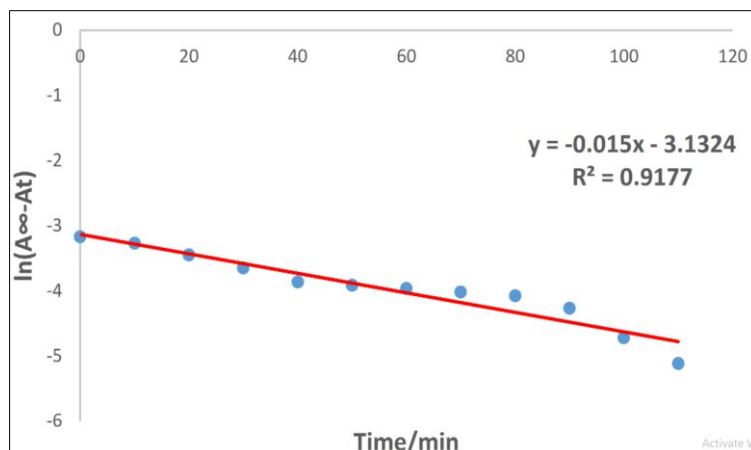


Fig 20: Thermal decomposition rate of compound (S7) in dioxane at Wavelength: 294nm

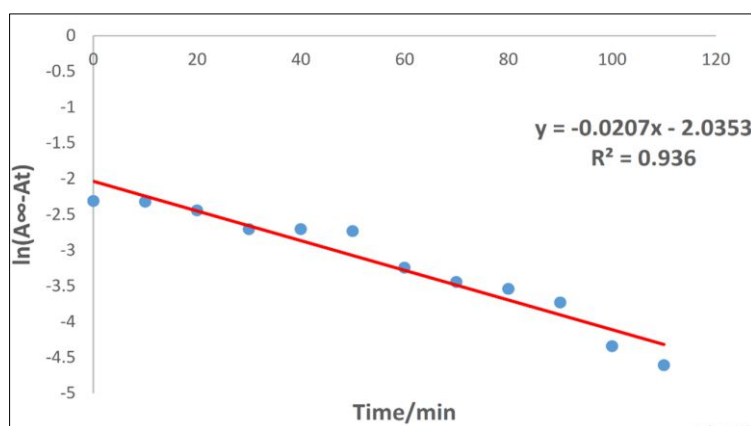


Fig 21: Thermal decomposition rate of compound (S8) in dioxane at Wavelength: 294 nm

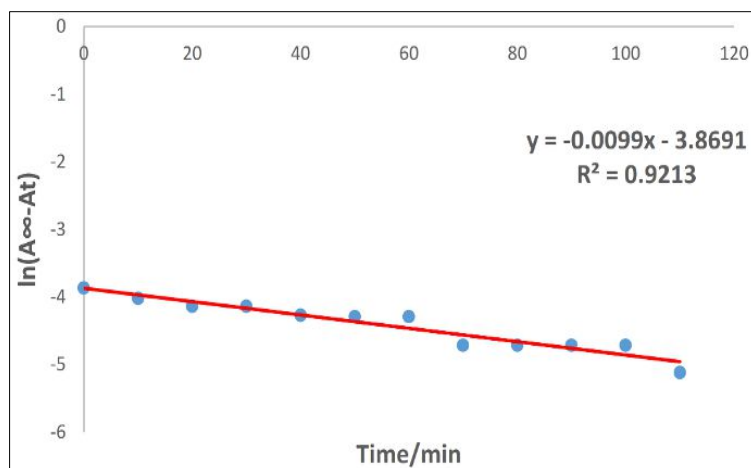


Fig 22: Thermal decomposition rate of compound (S9) in dioxane at Wavelength: 375 nm

Determination of the rate constant (k) for the reaction

The thermal decomposition of the re-arranged products of tertiary amine oxides was analyzed in dioxane at a wavelength of 294 nm to determine the rate constant (k) using first-order kinetics. Absorption measurements were taken at different time intervals ranging from 0 to 80 minutes. The relationship between the natural logarithm of the concentration difference, $\ln(A_{\infty} - A_t)$, and time (t) follows the equation:

$$\ln(A_{\infty} - A_t) = -kt + \ln(A_{\infty}) \dots \text{Eq.1}$$

The data were plotted with $\ln(A_{\infty} - A_t)$ versus time. A linear regression analysis of the plot yielded a straight line, where the slope represents the rate constant (k). Therefore, the rate constant (k) was calculated as: $k = -\text{Slope}$.

The value of the rate constant shown in Table 13 demonstrates the reaction speed under the specific conditions. The first-order kinetic behavior was confirmed by the linearity of the plot and the consistency of the calculated $\ln(A_{\infty} - A_t)$ values with time.

Table 13: The physical properties of synthesis rearrangement of the N-oxides (S7-S9).

Compound	Reaction order	Reaction rate constant, min ⁻¹
S7	First-order	1.497×10 ⁻²
S8	First-order	2.070×10 ⁻²
S9	First-order	9.40×10 ⁻³

Conclusion

The study successfully synthesized a series of aromatic tertiary amines and their oxides, and provided valuable kinetic data on the thermal rearrangement of these compounds. The combination of structural characterization and kinetic analysis using advanced spectroscopic techniques offered a comprehensive understanding of the chemical behaviors and transformations of these amine derivatives.

References

- Bernier D, Wefelscheid UK, Woodward S. Properties, preparation and synthetic uses of amine N-oxides. An update. *Org Prep Proced Int*. 2009;41(3):173–210. <https://doi.org/10.1080/00304940902955756>
- Wieczorek D, Kwasniewska D. Novel Trends in Technology of Surfactants. *Chemical Technologies and Processes*; Staszak, K., Wieszczycka, K., Tylkowski, B., Eds. 2020 Jul 20:23-50. <https://doi.org/10.1515/9783110656367-008>
- Hassabo AG, Saad F, Hegazy BM, Sediek A, Ghazal H. The use of cationic surfactants in the textiles industry. *Journal of Textiles, Coloration and Polymer Science*. 2023 Sep 1;20(2):227-242. <https://dx.doi.org/10.21608/jtpps.2023.216820.1189>
- Fabozzi A, Vitiello R, Russo Krauss I, Iuliano M, De Tommaso G, Amoresano A. Synthesis, surface properties, and self-aggregation behavior of a branched N, N-dimethylalkylamine oxide surfactant. *Journal of Surfactants and Detergents*. 2019 Jan;22(1):115-124. <https://doi.org/10.1002/jsde.12205>
- Kelland MA. Tailored Amine Oxides-Synergists, Surfactants, and Polymers for Gas Hydrate Management, a Minireview. *Energy & Fuels*. 2023 Jun 27;37(13):8919-8934. <https://doi.org/10.1021/acs.energyfuels.3c01365>
- Abdel-Halim NM, Soliman EA, El Dib FI, Mohamed AS, Mohamed DE. Synthesis and Evaluation of Some Amine Oxide Surfactants and Their Antimicrobial Activity. *Egyptian Journal of Chemistry*. 2024 Jan 1;67(1):101-109. <https://doi.org/10.21608/ejchem.2023.217783.8173>
- Yang L, Zhang X, Ma W, Raisi B, Liu X, An C. Trimethylamine N-oxide-derived zwitterionic polyamide thin-film composite nanofiltration membranes with enhanced anti-dye deposition ability for efficient dye separation and recovery. *Journal of Membrane Science*. 2023 Jan 5;665:121083. <https://doi.org/10.1016/j.memsci.2022.121083>
- Dai L, Guo Y, Su Z, Huang M, Chen QY, Zhao ZG. The surface properties of amine oxides with a fluoroether chain. *Journal of Fluorine Chemistry*. 2021 Jun 1;246:109793. <https://doi.org/10.1016/j.jfluchem.2021.109793>
- Didas SA, Choi S, Chaikittisilp W, Jones CW. Amine-oxide hybrid materials for CO₂ capture from ambient air. *Accounts of chemical research*. 2015 Oct 20;48(10):2680-2687. <https://doi.org/10.1021/acs.accounts.5b00284>
- Bollini P, Didas SA, Jones CW. Amine-oxide hybrid materials for acid gas separations. *Journal of Materials Chemistry*. 2011;21(39):15100-15120. <https://doi.org/10.1039/C1JM12522B>
- Ivanković T, Hrenović J. Surfactants in the environment. *Arhiv za higijenu rada i toksikologiju*. 2010 Mar 17;61(1):95-109. <https://doi.org/10.2478/10004-1254-61-2010-1943>
- Merrettig-Bruns U, Jelen E. Anaerobic biodegradation of detergent surfactants. *Materials*. 2009 Mar 16;2(1):181-206. <https://doi.org/10.3390/ma2010181>
- Battista S, Bellio P, Fagnani L, Allegritti E, Nazzicone L, Galantini L. Structurally Related Liposomes Containing N-Oxide Surfactants: Physicochemical Properties and Evaluation of Antimicrobial Activity in Combination with Therapeutically Available Antibiotics. *Molecular Pharmaceutics*. 2022 Feb 16;19(3):788-797. <https://doi.org/10.1021/acs.molpharmaceut.1c00609>
- Xiang J, Shen Y, Zhang Y, Liu X, Zhou Q, Zhou Z. Multipotent Poly(Tertiary Amine-Oxide) Micelles for Efficient Cancer Drug Delivery. *Adv Sci (Weinh)*. 2022 Apr;9(12):e2200173. <https://doi.org/10.1002/advs.202200173>
- Li D, Lu Y, Yuan S, Cai X, He Y. Gut microbiota-derived metabolite Trimethylamine-N-oxide (TMAO) and atherosclerosis. 2013;19(5):576-585. <https://doi.org/10.1093/ajcn/nqac074>
- Kobus M, Friedrich T, Zorn E, Burmeister N, Maison W. Medicinal Chemistry of Drugs with N-Oxide Functionalities. *Journal of Medicinal Chemistry*. 2024 Mar 29;67(7):5168-5184. <https://doi.org/10.1021/acs.jmedchem.4c00254>
- M. Al-Tufah M, Beebaeny S, Salem Jasim S, Lateef Mohammed B. Synthesis, Characterization of Ethyl Dioxoisindolinylnyl Cyclohexenone Carboxylate Derivatives from Some Chalcones and its Biological Activity Assessment. *Chemical Methodologies*, 2023;7(5):408-418. DOI: 10.22034/chemm.2023.388126.1654
- Al-Khazraji SI, Ahamed LS, Ali RA. Synthesis and Characterization of some new heterocyclic derivatives from aromatic carbonyl compounds and carboxylic acids with Evaluation some of them for biological activity. *Iraqi J Sci*. 2024;1855-1869. <http://dx.doi.org/10.24996/ijs.2024.65.4.6>
- SaadSalimJasim MG, Ghazei MF. Synthesis and Identification of some (pyrazole, pyridine-2-one, indazole and isoquinol-3-one) Compounds which derived from Chalcone and Evaluation of their Antibacterial. *Kirkuk Journal of Science*. 2018, 13(3)..