



(RESEARCH ARTICLE)



POLYAZOMETHINE–ZN(II) COMPLEXES WITH TUNABLE THERMAL, ELECTROCHEMICAL AND ANTIMICROBIAL PROPERTIES: SYNTHESIS, CHARACTERIZATION AND STRUCTURE–PROPERTY RELATIONSHIPS

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ABSTRACT

Polyazomethines are π -conjugated Schiff-base polymers whose azomethine nitrogen atoms provide coordination sites for metal ions and thereby offer a convenient route to multifunctional materials. In the present study, four aromatic polyazomethines were synthesized by condensation of p-phthalaldehyde with 4,4'-diaminodiphenyl ether (ODA), 4,4'-diaminodiphenylmethane (DDM), 4,4'-diaminodiphenyl sulfone (DDS), and p-phenylenediamine (PPD). Corresponding Zn(II)-containing polymeric complexes were prepared using ZnCl_2 under reflux conditions. The products were examined by Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), cyclic voltammetry (CV), and antimicrobial screening. FTIR spectra confirmed formation of the azomethine backbone through characteristic C=N stretching bands and showed additional changes attributable to Zn–N/Zn–O coordination. XRD indicated predominantly amorphous or weakly semicrystalline structures, while Zn incorporation increased the degree of local structural ordering, most markedly for the DDS- and PPD-derived systems. TGA demonstrated a clear improvement in thermal resistance after Zn coordination; the PPD-derived complex showed the highest reported thermal stability, with T_0 , T_{10} , T_{50} and T_{max} values of 346, 429, 547 and 600 °C, respectively, together with an 18% char residue. Cyclic voltammetry revealed scan-rate- and potential-window-dependent redox responses and generally good electrochemical cycling stability within the investigated ranges. Antimicrobial screening against *Staphylococcus aureus*, *Escherichia coli* and *Candida albicans* showed that the Zn-containing materials generally produced larger inhibition zones than their corresponding parent polymers, although the activity remained below that of the reference antimicrobial agents used in the study. Overall, the results demonstrate that Zn coordination provides an effective structural modification strategy for simultaneously tuning the thermal, electrochemical and antimicrobial characteristics of polyazomethines.

Keywords: Polyazomethine; Schiff-base polymer; Zn(II) complex; Azomethine; FTIR; XRD; TGA; DSC; Cyclic voltammetry; Antimicrobial activity.

1 INTRODUCTION

Polyazomethines (PAMs), also described as poly(Schiff-base)s, are an important class of functional polymers containing repeating azomethine ($-\text{CH}=\text{N}-$) linkages in the main chain. Their preparation is commonly based on condensation between aromatic diamines and aldehydes, allowing the molecular backbone to be modified systematically by changing the diamine or dialdehyde component. The combination of aromatic rigidity and conjugated imine linkages gives these polymers useful optical, thermal, electronic and coordination properties. Earlier studies on conjugated oligoazomethines and their metal complexes have demonstrated that metal coordination can alter thermal degradation, electrical conductivity and other physicochemical characteristics[1, 2].

The azomethine nitrogen atom is an efficient donor site and can participate in coordination with transition-metal ions. This feature is particularly useful because complexation changes the electronic environment of the polymer without requiring complete redesign of the polymer backbone. Studies of metal-containing azomethine and polyazomethine systems have shown that the nature of the metal, ligand donor set, backbone rigidity and flexible spacer groups can all influence the resulting thermal, optical, dielectric and electrochemical behavior [3]. A silicon-containing polyazomethine reported by Zaltariov et al., for example, formed Co(II), Cu(II) and Zn(II) complexes and displayed tunable thermal, optical, electrochemical and dielectric properties, illustrating the multifunctional potential of metal-containing azomethine polymers[4].

Zn(II) is particularly attractive for coordination-polymer design because it is a d10 ion and commonly forms stable coordination environments with N- and O-donor ligands. In biological contexts, zinc is an essential trace element, whereas in materials chemistry Zn(II) can modify chain packing, local rigidity and electronic interactions. The biological literature on Schiff-base metal complexes also indicates that metal coordination can increase antimicrobial activity relative to the corresponding uncomplexed ligand. This effect is often discussed in terms of changes in polarity and lipophilicity, membrane interaction, and the ability of the metal-containing framework to interact with cellular targets[5, 6]. Recent reviews continue to identify Schiff-base transition-metal complexes as an active area of antimicrobial materials research, while also emphasizing that activity depends strongly on ligand architecture, coordination geometry and the test system[7].

Electrochemical characterization provides another route for understanding how metal coordination modifies conjugated polymer systems. Cyclic voltammetry can be used to determine oxidation and reduction potentials, peak separation, current response and electrochemical stability. In conjugated azomethine systems, the observed electrochemical response may arise primarily from ligand-centered processes, metal–ligand electronic coupling, or a combination of charge-transfer pathways. Previous studies of azo-azomethine metal complexes have combined cyclic voltammetry with antimicrobial testing, illustrating the value of treating electrochemical and biological properties as complementary structure–function outputs rather than isolated characteristics[8].

The present work was designed around this multifunctional concept. Four structurally different diamine units—ODA, DDM, DDS and PPD—were selected to introduce ether, methylene, sulfone and rigid para-phenylene environments into the polyazomethine backbone. Each parent polymer was subsequently coordinated with ZnCl_2 . The resulting series provides a direct comparison of how backbone functionality influences structural organization, thermal stability, electrochemical behavior and antimicrobial performance. The thesis reports FTIR, XRD, TGA, DSC and CV characterization together with antimicrobial screening against representative Gram-positive, Gram-negative and fungal organisms. The central objective of the present journal article is therefore to establish a coherent structure–property relationship across the four Zn–polyazomethine systems.

The study is also relevant in the context of current research on multifunctional metal-based antimicrobial materials. Recent literature emphasizes that metal coordination can enhance biological activity but that apparent antimicrobial improvements should be interpreted carefully, particularly when only inhibition-zone data are available[9]. Accordingly, the present results are discussed as evidence of *in vitro* antimicrobial potential rather than as proof of therapeutic efficacy. Likewise, the electrochemical data are interpreted as evidence of redox/electroactive behavior within the tested potential windows, rather than as direct evidence of device performance.

2 MATERIAL AND METHODS

2.1 Chemicals and materials

The experimental work used p-phthalaldehyde as the dialdehyde component and four aromatic diamines: 4,4'-diaminodiphenylmethane (DDM), 4,4'-diaminodiphenyl ether (ODA), 4,4'-diaminodiphenyl sulfone (DDS), and p-phenylenediamine (PPD). Zinc chloride (ZnCl_2) was used as the source of Zn(II). Methanol and ethanol were used as reaction and washing solvents, while distilled water was used for washing and laboratory preparation. Dimethyl

sulfoxide (DMSO) was used to prepare solutions for antimicrobial testing. The thesis also reports use of Mueller–Hinton/nutrient agar media and standard reference antimicrobials for biological screening.

2.2 Synthesis of polyazomethines

The parent polyazomethines were prepared by condensation of equimolar p-phthalaldehyde and the selected aromatic diamine. The thesis specifies 5 mmol of each reactant and reflux in methanol for approximately 4–8 h, with thin-layer chromatography (TLC) used to monitor consumption of the starting materials. After completion, the solid product was recovered by filtration and washed repeatedly with distilled water and methanol. The four products were designated P1–P4 according to the diamine used. This condensation route is consistent with the general preparation of azomethine polymers through formation of C=N linkages between aldehyde and amine functionalities[1].

2.3 Preparation of Zn(II)-polyazomethine complexes

Zn-containing materials were prepared by introducing ZnCl_2 into the polyazomethine-forming reaction under reflux conditions. The thesis describes reaction of the diamine, p-phthalaldehyde and ZnCl_2 in ethanol, with TLC monitoring and subsequent filtration and washing of the solid product. The corresponding Zn-containing products were designated PC1–PC4. In the structural interpretation, coordination is assigned mainly to the azomethine nitrogen and oxygen donor sites where these are present in the relevant polymer backbone. The exact coordination number and molecular geometry were not determined by single-crystal X-ray diffraction in the reported work and therefore are not assigned here as definitive structural facts.

2.4 FTIR spectroscopy

FTIR spectra were recorded over $400\text{--}4000\text{ cm}^{-1}$ using a PerkinElmer spectrometer. The technique was used to identify the characteristic functional groups of the parent polymers and to monitor spectral changes following Zn coordination. Particular attention was given to the azomethine C=N stretching region and to lower-wavenumber bands attributed to metal–ligand interactions.

2.5 X-ray diffraction

Powder XRD patterns were recorded over a 2θ range of $5\text{--}80^\circ$. The thesis used XRD to assess crystallinity, phase organization and structural changes associated with metal coordination. The resulting patterns were interpreted mainly in terms of broad amorphous halos and the appearance or sharpening of weak crystalline reflections after Zn incorporation.

2.6 Thermogravimetric analysis

TGA was used to evaluate thermal resistance and decomposition behavior. The reported method involved 5–10 mg of sample, heating from 25 to $800\text{ }^\circ\text{C}$ at $10\text{ }^\circ\text{C min}^{-1}$ under nitrogen. The reported parameters include the initial degradation temperature (T_0), the temperature at 10% mass loss (T_{10}), the temperature at 50% mass loss (T_{50}), the maximum degradation temperature (T_{max}), and the final char residue.

2.7 Differential scanning calorimetry

DSC was used to compare thermal transitions and the principal endothermic decomposition regions of the Zn-containing polymers. The thesis interprets the major endothermic events as decomposition of the polymer backbone, with the position and intensity of the events varying with the diamine structure.

2.8 Cyclic voltammetry

Electrochemical measurements were performed in DMSO containing 0.1 M LiClO_4 as supporting electrolyte using a glassy-carbon working electrode, platinum-wire counter electrode and Ag/AgCl reference electrode under an inert atmosphere. Measurements were conducted at scan rates of 50 and 100 mV s^{-1} over potential windows of -1.0 to $+1.0\text{ V}$ and -1.5 to $+1.5\text{ V}$ for the Zn complexes. Additional measurements for the ODA and DDM systems explored a broader -2.5 to $+2.5\text{ V}$ window. The reported electrochemical parameters include anodic and cathodic peak potentials (E_{pa} and E_{pc}), peak separation (ΔE), anodic and cathodic currents, current ratios and CV-loop area.

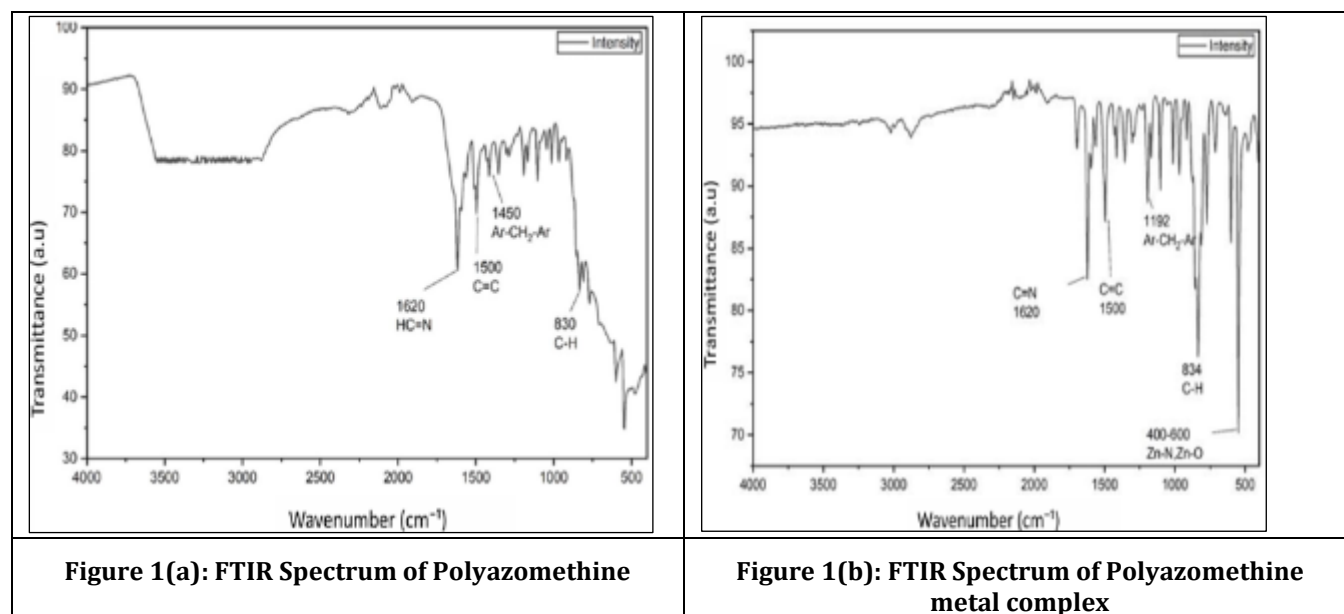
2.9 Antimicrobial assay

Antimicrobial screening was performed using a disk-diffusion procedure. The thesis reports preparation of microbial cultures adjusted to approximately 0.5 McFarland turbidity, application of 6 μL of each test solution corresponding to 1 mg of compound per disk, and incubation at $37\text{ }^\circ\text{C}$ for approximately 18–24 h. The organisms included *Staphylococcus aureus* (Gram-positive), *Escherichia coli* (Gram-negative) and *Candida albicans* (fungus). DMSO was used as the negative control; ofloxacin was used for the bacterial strains and clotrimazole for *C. albicans*. The inhibition-zone

diameters were then recorded. Because the thesis describes 6-mm filter-paper disks rather than agar wells, the present article refers to the experiment as a disk-diffusion assay. The current CLSI M02 standard provides a standardized framework for disk diffusion testing, although the present thesis experiment should not be considered fully CLSI-compliant without confirmation of all quality-control details[10].

3 RESULTS AND DISCUSSION

3.1 FTIR analysis



FTIR analysis provides the first direct evidence for formation of the polyazomethine backbone and for chemical modification after Zn incorporation. For the parent polymers, the thesis reports characteristic C=N stretching bands in the approximate 1615–1625 cm^{-1} region, together with aromatic C=C vibrations and bands associated with the specific bridging group of each diamine. In P1, the ether-containing system, an Ar–O–Ar vibration is reported around 1250 cm^{-1} , while the C=N and aromatic C=C bands occur near 1617 and 1510 cm^{-1} , respectively. P2 displays an Ar–CH₂–Ar feature near 1450 cm^{-1} and a C=N band around 1620 cm^{-1} . The DDS-based P3 shows bands associated with the sulfone group and the azomethine linkage, while the PPD-derived P4 shows the expected azomethine and para-substituted aromatic features.

After Zn incorporation, the spectra show systematic changes in the imine region and the emergence of low-wavenumber absorptions assigned in the thesis to Zn–N and Zn–O interactions. For PC1, the C=N stretching band is reported at approximately 1620 cm^{-1} and the C–O–C band near 1130 cm^{-1} shifts relative to the parent polymer. For PC2, the C=N band is reported around 1620 cm^{-1} and the Ar–CH₂–Ar environment changes. PC3 exhibits a C=N band around 1618 cm^{-1} and a shift in the sulfone-related vibration, whereas PC4 shows a C=N shift from approximately 1618 to 1605 cm^{-1} . These changes are consistent with modification of the electronic environment of donor groups following metal coordination.

The FTIR observations are chemically reasonable for a metal-coordination process involving donor atoms in the polymer backbone. Similar spectral changes are widely used to support coordination of transition metals to Schiff-base ligands, although FTIR alone cannot uniquely establish coordination geometry[4]. The present data therefore support formation of Zn-containing polyazomethine materials, while a more definitive structural assignment would require complementary elemental analysis, XPS, solid-state NMR or single-crystal analysis where applicable.

3.2 XRD analysis

The XRD results reveal that the parent polyazomethines are predominantly amorphous or weakly semicrystalline. The ODA–TPA system exhibits a broad halo in the 18–22° region, consistent with limited long-range order. The flexible ether linkage can hinder regular chain packing and therefore suppress development of extended crystalline domains. A similar predominantly amorphous character is reported for the DDM-based polymer, where the flexible methylene spacer reduces self-packing of the polymer chains.

The DDS- and PPD-based systems behave somewhat differently. The rigid sulfone-containing DDS backbone provides greater structural rigidity and more favorable local packing, while the para-phenylene unit in PPD provides a comparatively compact aromatic framework. After Zn incorporation, the thesis reports the appearance or sharpening of weak crystalline reflections in all systems, with the most pronounced increase in order for the DDS-derived complex and a clear but less extensive change for the PPD-derived material. ODA- and DDM-derived complexes remain largely amorphous despite the introduction of Zn.

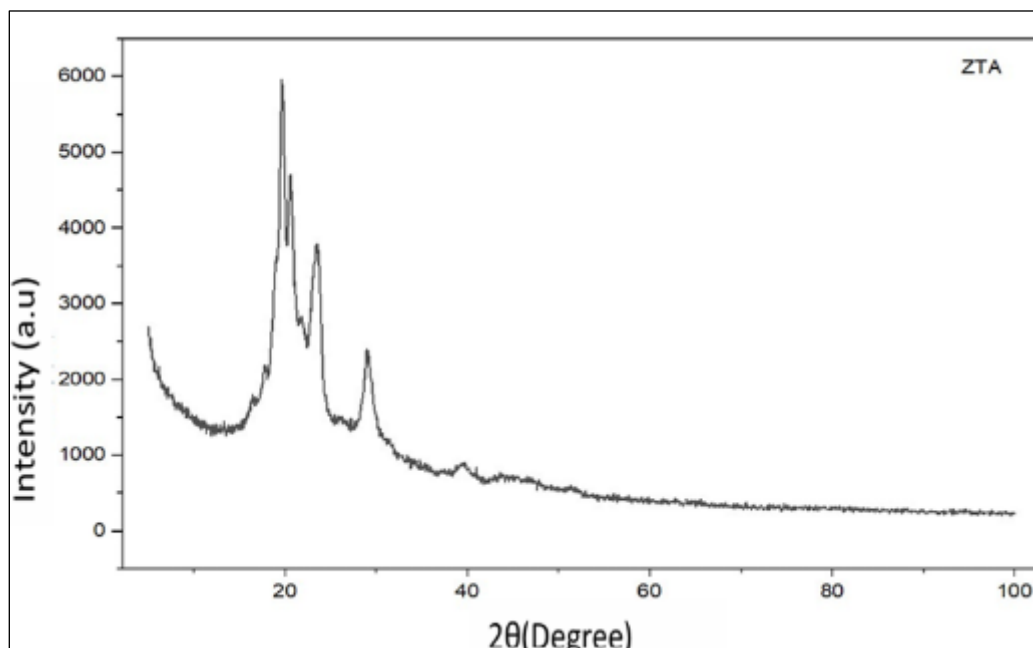


Figure 2: XRD Spectrum of Polyazomethine metal complex

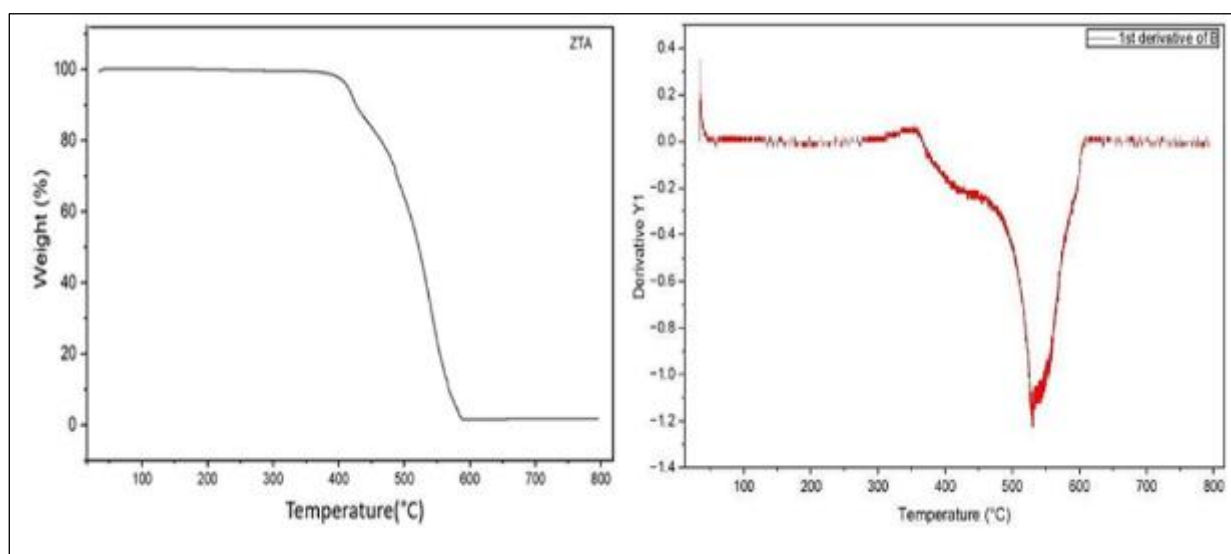
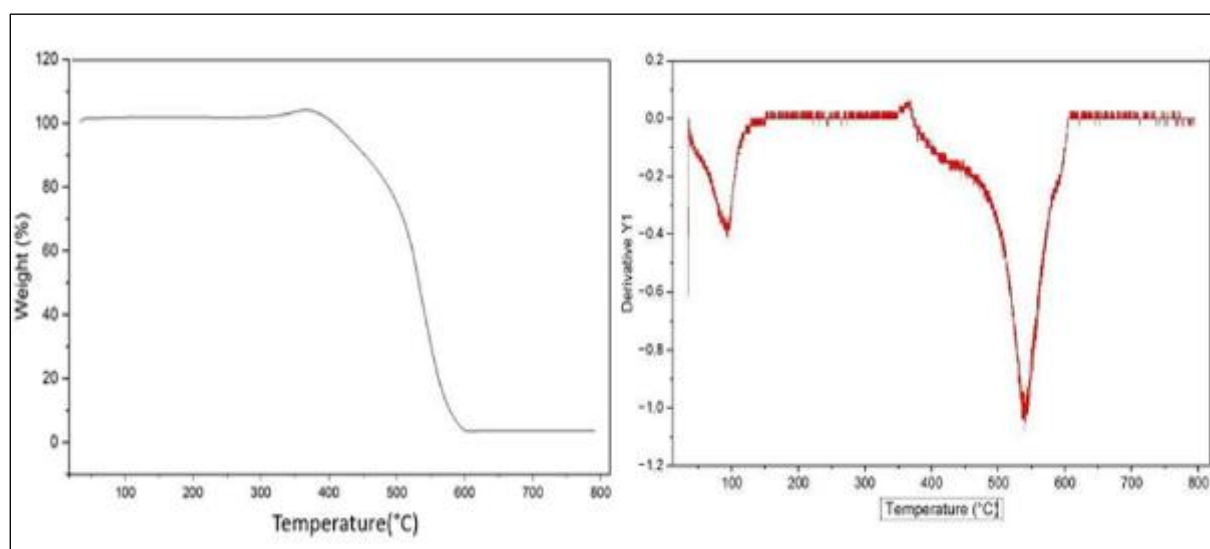
This trend can be rationalized in terms of the competition between metal-induced local ordering and the intrinsic flexibility of the polymer backbone. Zn coordination can restrict local chain motion and create additional interactions between polymer segments; however, a highly flexible spacer can still prevent long-range crystallization. In contrast, rigid aromatic or sulfone-containing backbones are better able to translate local coordination into a measurable increase in structural order. Similar relationships between backbone rigidity, metal coordination and the thermal/electronic behavior of azomethine materials have been reported in earlier polymer–metal studies[11].

3.3 Thermal stability from TGA

Thermal stability is one of the clearest areas in which Zn incorporation produces a measurable improvement. The thesis reports two-step thermal degradation behavior and provides T_0 , T_{10} , T_{50} , T_{max} and char-residue values for the four Zn-containing systems. Complex 1 (PC1) begins decomposition at 229 °C, reaches 10% mass loss at 302 °C, 50% mass loss at 447 °C, and a maximum degradation rate at 577 °C, with approximately 8% char residue. The corresponding values increase substantially for PC2 and PC3, while PC4 displays the highest values across the reported thermal parameters.

Table 1: Thermogravimetric parameters of the polyazomethine Zn complexes.

Sample	T ₀ (°C)	T ₁₀ (°C)	T ₅₀ (°C)	T _{max} (°C)	Char Residue (%)
Complex-1	229	302	447	577	8
Complex-2	336	372	429	583	11
Complex-3	338	374	434	585	14
Complex-4	346	429	547	600	18

**Figure 3: TGA and DTG of Polyazomethine metal complex****Figure 4: TGA and DTG of Polyazomethine metal complex**

The progression from PC1 to PC4 demonstrates that the nature of the diamine component strongly influences the thermal response of the coordinated polymer. PC4 exhibits the greatest thermal resistance, with $T_0 = 346\text{ }^{\circ}\text{C}$, $T_{10} = 429\text{ }^{\circ}\text{C}$, $T_{50} = 547\text{ }^{\circ}\text{C}$ and $T_{\text{max}} = 600\text{ }^{\circ}\text{C}$. Its 18% char residue is also the highest. The thesis attributes this behavior to stronger Zn–ligand interactions, increased chain restriction and the formation of a more thermally stable residue. The interpretation is consistent with the general principle that metal coordination can decrease polymer-chain mobility and increase the energy required for thermally induced structural rearrangement[12, 13].

The comparatively low T_0 of PC1 suggests that the ether-containing backbone is more susceptible to initial thermal degradation than the more rigid DDM-, DDS- and PPD-derived systems. PC2 and PC3 show similar onset behavior but progressively higher char formation, while PC4 combines high onset temperature with the highest T_{50} and T_{max} . The results therefore suggest that backbone rigidity and the chemical environment around the coordination sites are important determinants of the thermal response.

3.4 Differential scanning calorimetry

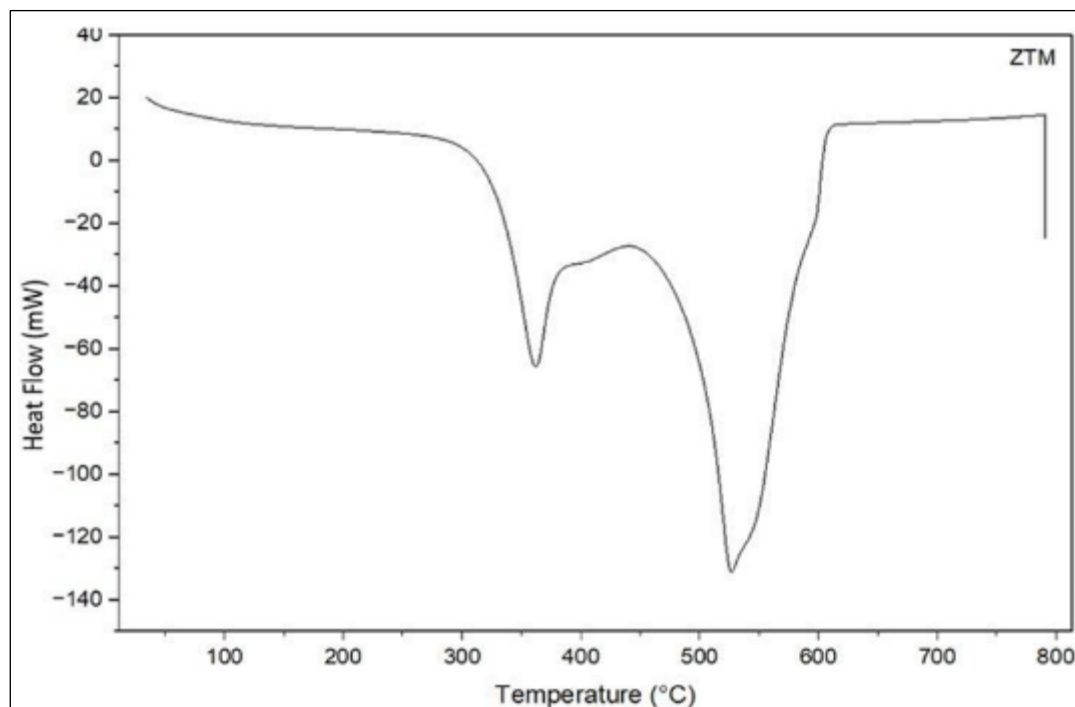


Figure 5: DSC of Polyazomethine metal complex

The DSC profiles provide complementary information on the thermal transitions of the Zn-containing systems. The ODA-based complex shows a principal endothermic decomposition region beginning approximately in the 350–420 $^{\circ}\text{C}$ range, with a strong feature around 410–430 $^{\circ}\text{C}$. The DDM-based material exhibits its principal endothermic event at a higher temperature, approximately within the 480–560 $^{\circ}\text{C}$ range. The DDS-based system shows the deepest and highest-temperature major endothermic event, estimated around 610–630 $^{\circ}\text{C}$. The PPD-based complex exhibits a sharp decomposition feature approximately between 400 and 470 $^{\circ}\text{C}$, followed by a broader high-temperature region associated with further breakdown and char-related processes.

The DSC results broadly support the TGA trend that backbone structure affects thermal resistance. In particular, the rigid sulfone-containing DDS framework produces a high-temperature DSC event, consistent with strong resistance to chain scission. The ODA system, which contains a flexible ether spacer, decomposes at comparatively lower temperature. The PPD system is structurally rigid but displays a distinct decomposition profile, demonstrating that rigidity alone does not determine the thermal response; donor-group environment, packing and coordination-induced structural constraints also contribute.

3.5 Cyclic voltammetry and electrochemical behavior

Cyclic voltammetry demonstrates that the Zn-polyazomethine materials are electroactive within the investigated potential windows. For PC1, the -1.0 to $+1.0\text{ V}$ window produces relatively broad anodic and cathodic responses. At 50 mV s^{-1} , E_{pa} and E_{pc} are reported as $+0.62$ and -0.54 V , respectively, giving $\Delta E = 1.16\text{ V}$; the anodic and cathodic currents are 3.2 and $2.5\text{ }\mu\text{A}$. At 100 mV s^{-1} , the peak currents increase to 4.8 and $3.7\text{ }\mu\text{A}$ while the peak separation remains

approximately 1.16 V. When the window is expanded to -1.5 to $+1.5$ V, the CV area increases substantially, consistent with access to a larger electroactive potential range.

PC2 shows a similar scan-rate dependence. In the -1.0 to $+1.0$ V window, the reported anodic peak shifts from $+0.65$ to $+0.63$ V when the scan rate increases from 50 to 100 mV s^{-1} , while the cathodic peak shifts from -0.56 to -0.59 V. The corresponding peak currents increase from $3.6/2.8$ to $5.2/4.0\text{ }\mu\text{A}$. In the wider window, the CV area rises to $0.56\text{ }\mu\text{C}$ at 50 mV s^{-1} and $0.95\text{ }\mu\text{C}$ at 100 mV s^{-1} . PC3 follows a closely related pattern, with ΔE around 1.18 V in the narrow window and approximately 1.38 – 1.40 V in the wider window.

The PPD-derived PC4 differs from the other complexes because the thesis evaluates narrower windows, -1.0 to 0.0 V and 0.0 to $+1.0$ V, rather than a symmetric ± 1.5 V window. The reported peak separations are 0.36 – 0.40 V, with current responses increasing at 100 mV s^{-1} . Repeated cycling produced nearly overlapping traces, which the thesis interprets as evidence of electrochemical stability within the tested potential intervals.

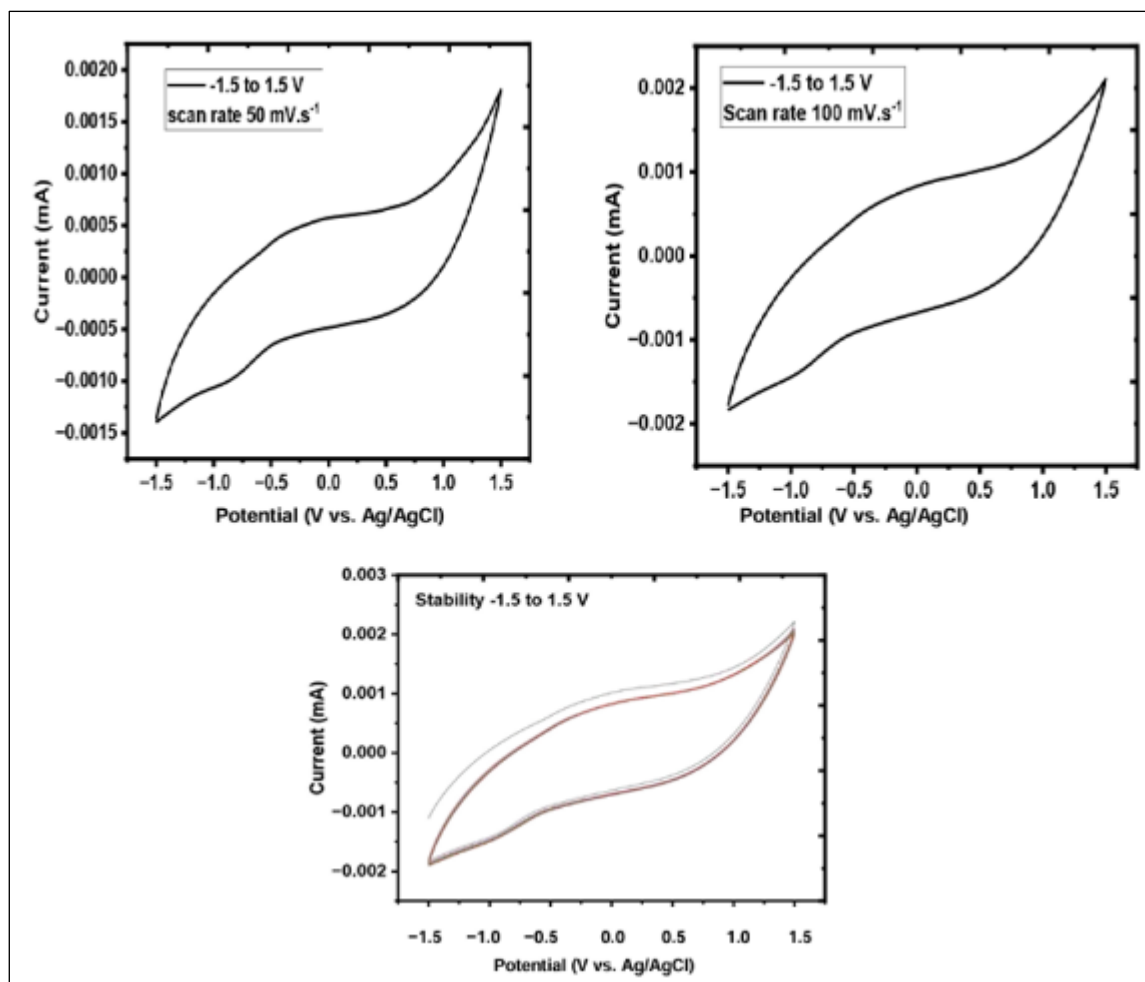


Figure 6: Cyclic voltammogram of Polyazomethine Zinc-complex (PC1)

The increase in current response with scan rate is consistent with faster electrochemical response at the higher sweep rate, while the persistence of the general CV shape during repeated cycling supports reasonable stability in the investigated windows. Such behavior is consistent with the established use of CV for evaluating electron-transfer behavior, redox reversibility and electrochemical stability in conjugated polymers and metal-containing molecular materials[11, 14].

A caution is required regarding interpretation of reversibility. Large ΔE values, especially those around 1.2 – 1.4 V for PC1–PC3, indicate substantial peak separation and should not be described as ideal reversible behavior. The thesis uses the term “quasi-reversible,” but a rigorous assignment would require consideration of scan-rate dependence, formal potentials, peak-current ratios and, ideally, diffusion analysis. The present article therefore uses the more conservative description “quasi-reversible or kinetically non-ideal redox behavior” where appropriate. This distinction strengthens the scientific interpretation without altering the experimental observations.

Table 2: Cyclic voltammetry data of Polyazomethine Zinc-complex

Potential Window (V)	Scan Rate (mV/s)	E _{pa} (V)	E _{pc} (V)	ΔE (V)	i _{pa} (μA)	i _{pc} (μA)	i _{pa} /i _{pc}	CV Area (μC)
–1.0 to +1.0	50	+0.62	–0.54	1.16	3.2	2.5	1.28	0.15
–1.0 to +1.0	100	+0.60	–0.56	1.16	4.8	3.7	1.29	0.24
–1.5 to +1.5	50	+0.58	–0.78	1.36	5.1	4.2	1.21	0.48
–1.5 to +1.5	100	+0.55	–0.80	1.35	7.4	6.0	1.23	0.85

3.6 Antimicrobial activity

The antimicrobial experiments demonstrate that Zn incorporation can improve the inhibitory effect of the polyazomethine materials. The study examined *S. aureus*, *E. coli* and *C. albicans* using disk diffusion. Among the parent polymers, P1 produced the highest inhibition zones for all three tested organisms, with reported values of 7 ± 0.01 against *E. coli*, 7 ± 0.02 against *S. aureus* and 6 ± 0.01 against *C. albicans*. The Zn-containing PC1 increased these values to 9 ± 0.01 , 9 ± 0.02 and 7 ± 0.01 , respectively.

Table 3: Antimicrobial activity of Polyazomethines and polyazomethine metal complex

Compound code	Gram negative bacteria	Gram positive bacteria	Fungal
	<i>E. coli</i>	<i>S. aureus</i>	<i>C. albicans</i>
P1	7±0.01	7±0.02	6±0.01
P2	5±0.01	5±0.01	5±0.01
P3	6±0.01	6±0.02	5±0.01
P4	6±0.02	5±0.02	5±0.01
PC1	9±0.01	9±0.02	7±0.01
PC2	7±0.02	7±0.01	6±0.01
PC3	8±0.01	8±0.02	7±0.01
PC4	7±0.02	8±0.02	7±0.01
DMSO	----	----	----
Ofloxacin	13±0.01	12±0.01	----
Clotrimazole	----	----	15±0.01

PC2 showed moderate activity relative to the other Zn complexes, whereas PC3 and PC4 produced intermediate inhibition zones. PC4 was particularly notable against *C. albicans* relative to some of the other Zn-containing systems. The overall bacterial trend indicates greater sensitivity of *S. aureus* than *E. coli* for several of the tested materials. This

observation is compatible with the general difference between Gram-positive and Gram-negative envelope structures, although the present study does not provide mechanistic evidence sufficient to attribute the effect to a single cellular pathway.

The Zn-containing systems remained less active than the reference agents. Ofloxacin produced inhibition zones of 13 ± 0.01 and 12 ± 0.01 against *E. coli* and *S. aureus*, respectively, while clotrimazole produced 15 ± 0.01 against *C. albicans*. The comparison is useful because it places the experimental materials in context: the Zn-polyazomethines demonstrate measurable antimicrobial potential, but their activity in the present assay does not approach that of the reference drugs. This is consistent with the broader literature, in which Schiff-base metal complexes frequently show enhanced activity after metal coordination but can remain weaker than established antimicrobial agents [15].

The thesis interprets the improvement after Zn coordination using chelation theory. Coordination can reduce the effective charge density at the metal center and alter the overall polarity and lipophilicity of the complex, potentially facilitating interaction with microbial membranes. Related studies on Zn(II) Schiff-base complexes have proposed enhanced membrane interaction and other cellular effects as contributors to antimicrobial activity [15, 16]. However, the present disk-diffusion experiment does not establish the molecular mechanism. The observed inhibition zones should therefore be described as evidence of antimicrobial activity rather than direct evidence of membrane disruption, enzyme inhibition, DNA interaction or reactive oxygen species generation.

The biological results also highlight an important structure–activity relationship. PC1, derived from the ether-containing ODA backbone, exhibits the strongest antibacterial performance among the Zn-containing series for both *E. coli* and *S. aureus*. PC4, in contrast, shows a relatively favorable response toward *C. albicans*. These differences indicate that the identity and flexibility of the bridging group can influence biological interactions. The result is consistent with the broader literature showing that ligand substitution and coordination geometry can substantially alter the biological activity of metal–Schiff-base systems [17].

4 CONCLUSION

A comparative series of polyazomethine polymers and their Zn(II)-containing complexes was successfully prepared from p-phthalaldehyde and four aromatic diamines containing ether, methylene, sulfone and para-phenylene structural units. FTIR spectroscopy confirmed the formation of the azomethine backbone and revealed systematic spectral changes after Zn incorporation, supporting coordination through donor sites in the polymer framework. XRD showed that the parent polymers were predominantly amorphous or weakly semicrystalline and that Zn coordination promoted additional local ordering, most clearly in the DDS- and PPD-derived systems. Thermal analysis demonstrated a substantial enhancement in thermal resistance after Zn coordination. Among the studied materials, PC4 displayed the highest reported thermal stability, with $T_0 = 346\text{ }^\circ\text{C}$, $T_{10} = 429\text{ }^\circ\text{C}$, $T_{50} = 547\text{ }^\circ\text{C}$ and $T_{\text{max}} = 600\text{ }^\circ\text{C}$, together with an 18% char residue. DSC measurements further showed that backbone chemistry strongly influences the temperature and shape of the principal decomposition events. These findings indicate that the combination of aromatic rigidity and Zn coordination can be used to improve thermal endurance of polyazomethine materials. Electrochemical measurements showed potential-dependent redox responses and increasing current with scan rate. Repeated cycles were largely overlapping within the investigated windows, indicating useful electrochemical stability under the experimental conditions. The data support the presence of electroactive conjugated frameworks whose response is modified by Zn coordination, although the relatively large peak separations for several systems indicate kinetically non-ideal behavior rather than ideal reversibility.

The antimicrobial experiments showed that Zn coordination generally increased the inhibition-zone response compared with the corresponding parent polymers. PC1 displayed the strongest bacterial response among the Zn-containing materials, while PC4 showed comparatively favorable activity toward *C. albicans*. Nevertheless, the reference drugs produced larger inhibition zones, demonstrating that the synthesized materials should not yet be regarded as replacements for established antimicrobial agents. Instead, they represent multifunctional polymeric platforms worthy of further biological and materials investigation. Future work should strengthen the structure–property relationships by incorporating elemental analysis and surface-sensitive techniques such as XPS, direct morphology/elemental mapping by SEM–EDS or TEM where appropriate, quantitative molecular-weight measurements, MIC/MBC testing, time-kill assays, cytotoxicity/biocompatibility measurements, and more rigorous electrochemical kinetic analysis. Such experiments would help distinguish correlation from mechanism and would substantially improve the translational value of the Zn-polyazomethine platform.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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