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Thermal Behavior and Decomposition Kinetics of Novel Copolymer

Akshay A. Akare[1], W. B. Gurnule[2], Satendra M. Sontakke[3], Jyotsna V. Khobragade[4] and D. M. Chafle[1]

[1]Department of Chemistry, Taywade College, Mahadula, Koradi, Nagpur, India.
[*2]Department of Chemistry, Kamla Nehru Mahavidyalaya, Nagpur-, India.
[3]Department of Chemistry, M. G. Arts, Science and Late N. P. Commerce College, Armori, India.
[4]Department of Chemistry, GuruNanak College of Science, Ballarpur, India.
akshayakare10@gmail.com, wbgurnule@gmail.com

Abstract: *In this study, a novel multifunctional copolymer was synthesized via a controlled polycondensation reaction involving 8-hydroxyquinoline-5-sulphonic acid, acrylamide, and formaldehyde. Structural characterization was carried out using Fourier-transform infrared (FTIR) spectroscopy, UV–Visible spectroscopy, and proton nuclear magnetic resonance (1H NMR), all of which confirmed the successful incorporation of functional groups into the polymer backbone. Molecular weight parameters, including the number-average (Mn) and weight-average (Mw) molecular weights, were determined by gel permeation chromatography (GPC), revealing relatively high molecular weights with a low polydispersity index, indicative of structural uniformity and compatibility with thermally stable polymer frameworks. X-ray diffraction (XRD) analysis showed a semi crystalline pattern, while scanning electron microscopy (SEM) revealed a uniform and porous surface morphology. Thermal behavior was systematically examined through thermogravimetric analysis (TGA), and kinetic parameters such as activation energy (Ea) were calculated using the Freeman–Carroll and Sharp–Wentworth models. These consistent results highlighted the copolymer's remarkable thermal stability. Collectively, the material demonstrates excellent thermal resilience, well-defined structural features, and favorable morphological characteristics, positioning it as a promising candidate for advanced high-temperature applications and demanding materials engineering environments.*

Keywords: Copolymer, Spectral, Surface study, Thermal study, Thermodynamic properties

I. INTRODUCTION

Copolymers, constructed from two or more distinct monomeric units, have emerged as one of the most dynamic classes of polymeric materials due to their exceptional structural versatility and functional adaptability. Through precise molecular design, diverse monomeric species can be integrated into a single polymer framework, enabling the unification of properties such as mechanical robustness, chemical resistance, processability, and thermal stability. This inherent tunability not only enhances performance under demanding conditions but also broadens the scope of their applications. As a result, copolymers play a pivotal role in the development of next-generation materials, driving innovation across fields ranging from protective coatings and high-performance adhesives to biomedical devices, sustainable technologies, and advanced electronic components.

Thermal stability is a decisive factor governing the performance and reliability of polymeric materials, particularly in applications exposed to elevated temperatures. The incorporation of aromatic moieties, crosslinked networks, and thermally robust linkages within copolymer backbones greatly enhances their resistance to thermal degradation. Consequently, thermally stable copolymers are increasingly engineered for high-demand sectors such as aerospace, automotive, electronics, and industrial insulation, where materials must retain structural integrity and functional efficiency under heat stress [1–2]. In this context, Gurnule and coworkers investigated the high-temperature

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degradation of a newly synthesized copolymer based on 1,5-diaminonaphthalene, 2-hydroxy-4-methoxybenzophenone, and formaldehyde, reporting significant insights into its stability and decomposition behavior [3]. A thermally stable copolymer was synthesized through bulk polymerization of phenylhydrazine, 2,4-dihydroxybenzoic acid, and formaldehyde in a 3:1:5 molar ratio, employing an acid catalyst to promote the reaction. Its thermal performance was comprehensively evaluated to assess structural resilience under heat stress [4–6]. Copolymers and their corresponding polychelates, recognized for their remarkable thermal endurance, continue to play a pivotal role in the development of high-performance polymeric materials for advanced technological applications [7]. Notably, Rathod and coworkers reported that the incorporation of metal ions into a copolymer resin significantly reduced its thermal stability, underscoring the pronounced effect of metal coordination on degradation pathways [8–10]. Rahangdale et al carried out an in-depth thermogravimetric investigation of a copolymer synthesized from 2-hydroxy-4-methoxybenzophenone, 1,5-diaminonaphthalene, and formaldehyde, yielding valuable insights into its thermal stability profile [11]. Similarly, thermal decomposition analysis of the 2-amino-6-nitrobenzothiazole–oxamide–formaldehyde copolymer demonstrated a notable improvement in thermal stability, attributed to the higher formation of carbonaceous residue, as confirmed by TGA results [12–13]. Furthermore, polymers subjected to high-temperature thermal studies were systematically examined using thermogravimetric analysis, providing detailed information on their decomposition mechanisms and heat-resistance characteristics [14–15].

The present study focuses on the synthesis and characterization of a novel copolymer, 8-hydroxyquinoline-5-sulphonic acid–acrylamide–formaldehyde (8-HQ5-SAAF-II), prepared through the polycondensation method. The thermal behavior of the copolymer was systematically investigated using thermogravimetric analysis (TGA), while elemental analysis and a range of spectroscopic techniques were employed to confirm its structural features. Surface morphology was examined using scanning electron microscopy (SEM), and X-ray diffraction (XRD) analysis was performed to determine its crystalline or amorphous nature. In addition, activation energy, along with relevant kinetic and thermodynamic parameters, was calculated to provide comprehensive insights into the thermal stability of the copolymer.

II. EXPERIMENTAL

All compound and chemicals (8-hydroxyquinoline-5-sulphonic acid, acrylamide, formaldehyde, Dimethyl sulfoxide, N, N-dimethylformamide, Hydrochloric acid) used in this study were of analytical grade and were utilized devoid of any additional purification, by Central Scientific Company, Nagpur.

Synthesis of Copolymer

The 8-HQ5-SAAF-III copolymer was synthesized via a controlled polycondensation reaction of 8-hydroxyquinoline-5-sulphonic acid, acrylamide, and formaldehyde in the presence of 2 M hydrochloric acid as a catalyst. The reaction mixture was refluxed at 125 °C for 5h, producing a yellow resinous product. The crude polymer was purified initially by successive washings with diethyl ether and distilled water. For further purification, the material was dissolved in 8% (w/v) sodium hydroxide and reprecipitated gradually using a concentrated HCl water mixture. The obtained solid was dried, finely ground, and sieved to yield a uniform powder. Solubility studies revealed excellent miscibility of the copolymer in polar aprotic solvents such as DMSO, DMF, and THF, confirming its strong compatibility with organic media. Conversely, its limited solubility in mineral acids suggests minimal interaction under strongly acidic conditions, further validating the structural integrity and stability of the material. The reaction sequence for the synthesis of the newly prepared 8-HQ5-SAAF-III copolymer is illustrated in Scheme 1.

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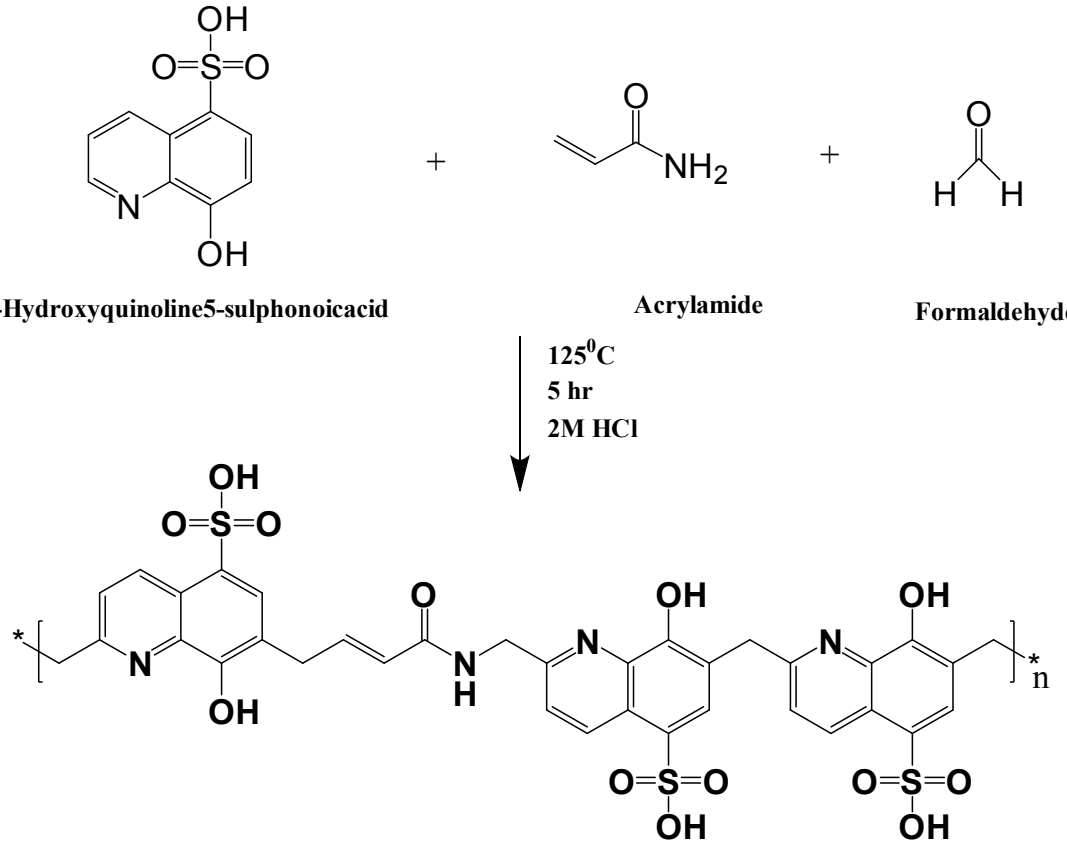

Scheme 1. Configuration and suggested structure of 8-HQ5-SAAF-III Copolymer

Instruments

Comprehensive physicochemical and structural characterization of the synthesized copolymer was performed using a suite of advanced analytical techniques. Elemental analysis was carried out on a Perkin Elmer 789N QP-2010 instrument to determine the precise composition. Molecular weight and its distribution were evaluated by Gel Permeation Chromatography (GPC) using tetrahydrofuran (THF) as the mobile phase at a constant flow rate of 1 mL/min, with the system calibrated against polystyrene standards for accuracy. UV–Visible spectroscopy was conducted in DMSO over the 200–800 nm range to probe electronic transitions, while Fourier-transform infrared (FTIR) spectra were recorded in the 4000–500 cm^{-1} region using KBr pellets to identify functional groups. Structural elucidation was further supported by proton nuclear magnetic resonance (^{1}H NMR) spectroscopy, recorded in DMSO-d□ on a 400 MHz Bruker spectrometer. Surface morphology was examined by Scanning Electron Microscopy (SEM), and crystalline characteristics were assessed through X-ray Diffraction (XRD) analysis. Thermal behavior and degradation kinetics were systematically investigated using a Perkin Elmer TGA thermal analyzer.

Physico-chemical characteristics

Key physicochemical parameters of the synthesized copolymer—such as void volume fraction, solid content, true density, moisture content, and sodium exchange capacity—were systematically determined using established literature protocols. These evaluations offered critical insights into the structural integrity and functional performance of the resin, underscoring its suitability for separation and purification applications.

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Moisture Content Determination (in %)

To determine the moisture content, 0.30 g of the copolymer was immersed in 35 mL of distilled water for 46 h to ensure complete swelling. The swollen sample was filtered, and excess surface water was gently removed using filter paper. The wet weight of the swollen polymer was then recorded. Subsequently, the sample was dehydrated in a hot air oven at 90–98 °C for 8 h, cooled to room temperature, and reweighed. The moisture content (%) was calculated from the difference between the swollen and dry weights.

The solid content (%)

$$\text{Solid content (\%)} = (W_d/W_b) \times 100 \text{---------- (1)}$$

Where:

Wd = Dried material (g)

Wb = Material before drying (g)

Moisture Content Calculation

The moisture content in percentage was examine using this equation

$$\text{Moisture content percentage} = 100 - \text{Solid (\%)} \text{ ---------- (2)}$$

True density

$$\text{True density} = \frac{Wp-W}{(Ww-Wpw)+(Wp-Ww)} \text{ ---------- (3)}$$

Where:

W = mass of empty bottle

Wp = mass of bottle with sample

Ww = mass of bottle with water

Wpw = mass of bottle with polymer and water

Volumetric Density

$$\text{Volumetric density} = \frac{\text{Weight of sample}}{\text{Volume of sample}} \text{ ---------- (4)}$$

Assessment of Physical Properties

The fundamental physical properties of the synthesized copolymer—including solid content, moisture content, true density, and volumetric density—were systematically evaluated following standardized protocols. These procedures, adapted from established literature methods, ensured methodological consistency while enhancing the reliability and reproducibility of the experimental outcomes.

Thermal analysis

Thermogravimetric analysis (TGA) was employed to investigate the thermal resistance and stepwise degradation behavior of the synthesized copolymer. The analysis provided detailed insights into its decomposition profile across a controlled temperature range. Key kinetic and thermodynamic parameters, including activation energy and entropy change, were derived from the TGA data using two well-established non-isothermal kinetic models: the Freeman–Carroll (FC) and Sharp–Wentworth (SW) methods. The use of these complementary approaches enabled a comprehensive evaluation of the copolymer's thermal performance, underscoring its potential for applications demanding high thermal stability.

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III. RESULTS & DISCUSSION

Elemental Analysis of 8-HQ5-SAAF-II copolymer

Elemental composition analysis of the synthesized 8-HQ5-SAAF-II copolymer was performed using microanalytical techniques to quantify carbon (C), hydrogen (H), nitrogen (N), and sulfur (S). This assessment verified the stoichiometric accuracy and structural fidelity of the copolymer in accordance with its proposed molecular architecture. The experimentally obtained elemental percentages were in close agreement with the theoretically calculated values, thereby confirming the successful synthesis of the intended structure. From these results, the empirical formula of the copolymer was established, and the molecular weight of a single repeating unit was precisely determined. A comparative summary of the theoretical and experimental elemental data is presented in Table 1, further validating the structural consistency of the polymer.

Table 2: Elemental Analysis of 8-HQ5-SAAF-II copolymer

Copolymer	Carbon (%) Experimental Theoretical	Hydrogen (%) Experimental Theoretical	Nitrogen (%) Experimental Theoretical	Sulphur (%) Experimental Theoretical	Empirical Formula (Per Repeating Unit)	Molecular Weight of Repeating Unit (g/mol)
8-HQ5-SAAF-III	52.49 (51.83)	3.11 (4.18)	6.42 (8.37)	7.62 (9.57)	$C_{22}H_{22}N_3O_{10}S_2$	568

Molecular Weight Determination of 8-HQ5-SAAF-III Copolymer

The molecular weight of the synthesized copolymer was determined using Gel Permeation Chromatography (GPC), a reliable technique that evaluates molecular weight distribution by separating polymer chains according to their hydrodynamic volume in solution. Tetrahydrofuran (THF) was employed as the mobile phase at a constant flow rate of 1 mL/min. Calibration was performed using a series of polystyrene standards with well-defined molecular weights, enabling the construction of a precise calibration curve. The molecular weight of the copolymer was subsequently calculated by referencing this standard curve. Key parameters, including the number-average molecular weight (Mn), are summarized in Table 2, offering critical insights into the copolymer's molecular architecture and distribution profile.

Table 2: Molecular Weight determination of 8-HQ5-SAAF-III Copolymer

Copolymer	**Molar Mass of Repeating Unit (g/mol)**	**Number average molecular weight ($\bar{}_{Mn}$)**
8-HQ5-SAAF-II	568	9608

Spectral studies

UV–Visible Spectroscopic Analysis of 8-HQ5-SAAF-III Copolymer

The UV–Visible absorption spectrum of the 8-HQ5-SAAF-III Copolymer, recorded in pure DMSO (Fig. 2), was scanned over a wavelength range of 200–850 nm at a rate of 100 nm/min. The spectrum exhibited two distinct absorption bands: a prominent peak in the region of 360–370 nm and a secondary band between 240–260 nm. The stronger absorption band is ascribed to $\pi \rightarrow \pi^*$ electronic transitions characteristic of aromatic ring systems, whereas the weaker band corresponds to $n \rightarrow \pi^*$ transitions, arising from –OH and –NH functional groups present on the side chains. A hypochromic shift was also observed, attributed to the role of these functional groups as auxochromes, which enhance absorption intensity [16].

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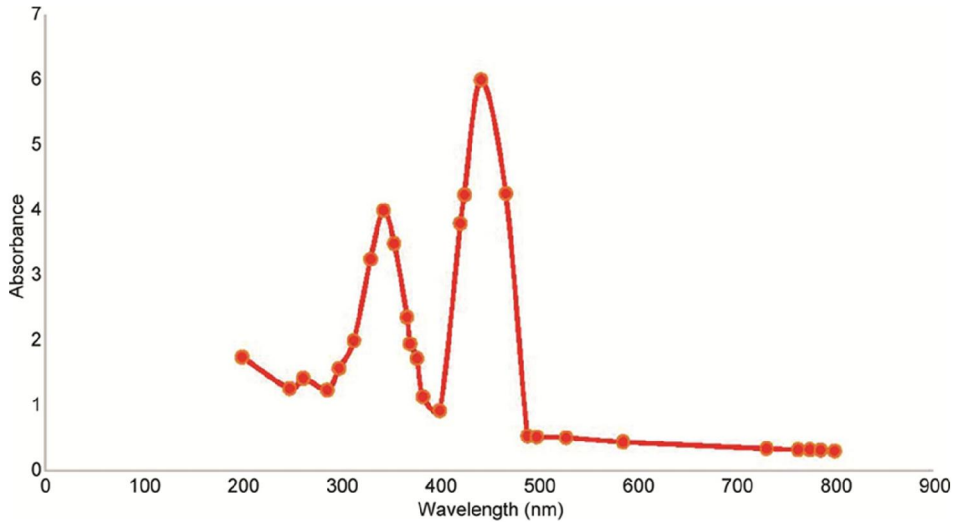

Figure 2. Ultraviolet–Visible Absorption Spectrum of 8-HQ5-SAAF-III Copolymer

FTIR Spectroscopic Analysis of 8-HQ5-SAAF-III copolymer

The FTIR spectrum of the synthesized copolymer (Fig. 5), with corresponding absorption band assignments summarized in Table 4, provides clear evidence of its structural features. A broad band observed in the 3506–3508 cm^{-1} region is attributed to O–H stretching vibrations of phenolic hydroxyl groups, suggesting possible intramolecular hydrogen bonding [17]. A sharp and intense peak in the 1556–1626 cm^{-1} range corresponds to aromatic skeletal vibrations, while absorption bands in the 1210–1230 cm^{-1} region confirm the presence of methylene (–CH□) bridging linkages [18]. Additional medium-to-weak intensity bands at 953–970 cm^{-1}, 1046–1145 cm^{-1}, 1182–1188 cm^{-1}, and 1320–1321 cm^{-1} are characteristic of 1,2,3,5-substitution patterns on the benzene ring. Furthermore, a distinct absorption band in the 3393–3402 cm^{-1} region is assigned to –NH stretching vibrations of bridging amino groups, overlapping with the broad O–H stretch and thereby confirming the coexistence of phenolic and amino functionalities within the copolymer backbone.

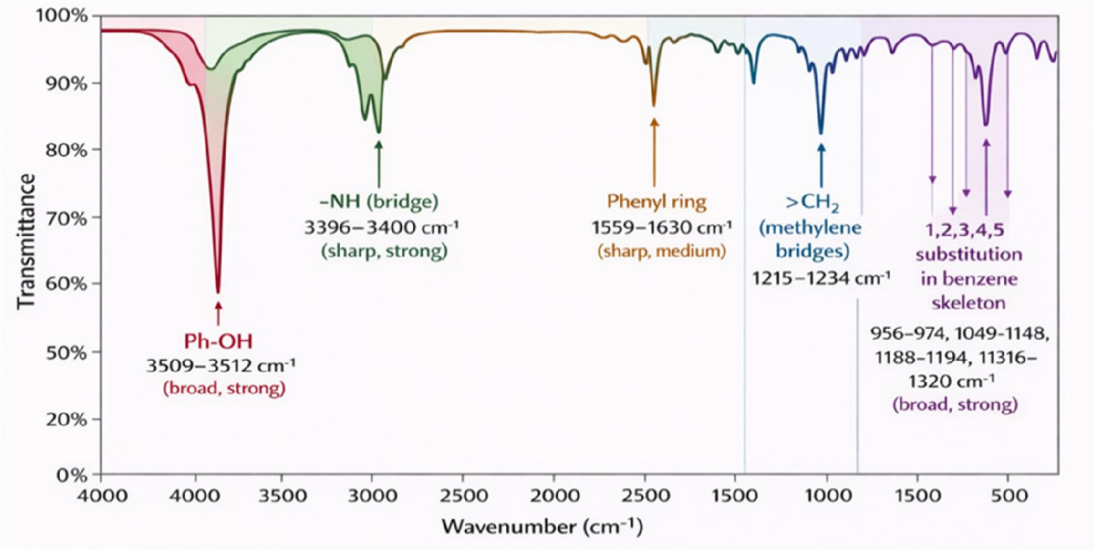

Figure 3: FTIR Spectroscopic Spectrum of 8-HQ5-SAAF-III Copolymer

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Table 2: FT- IR spectral data of 8-HQ5-SAAF-III Copolymer

Assignment	Predicted Vibrational Frequency (cm^{-1})	Measured IR Band Position (cm^{-1})
Ph-OH	3100-3500	3506-3508 (broad, strong)
-NH (bridge)	3500-3300	3393-3402 (sharp, strong)
Phenyl ring	1445-1485	1556-1626 (sharp, medium)
$>CH_2$ (methylene bridges)	1250-1360	1210-1230 (weak, medium)
1,2,3,4,5 substitution in benzene skeleton	557.9-900	953-970, 1046-1145, 1182-1188, 1320-1321 (broad ,strong)

^{1}H NMR Spectral Analysis of 8-HQ5-SAAF-III copolymer

The ^{1}H NMR spectrum of the synthesized 8-HQ5-SAAF-III copolymer (Fig. 4), with corresponding spectral assignments summarized in Table 4, was recorded in DMSO-d□ as the deuterated solvent and interpreted with support from literature references [19–20]. A singlet at δ 4.96–4.98 ppm is attributed to methylene (–CH□–) protons adjacent to the Ph–CH□–N linkage. Resonances observed in the δ 7.35–7.41 ppm region correspond to –NH bridging protons. Weak, unsymmetrical multiplets at δ 8.20–8.25 ppm are assigned to aromatic (Ar–H) protons, while distinct signals in the δ 9.02–9.06 ppm range are characteristic of phenolic –OH protons. The pronounced downfield shift of the hydroxyl signals indicates strong intramolecular hydrogen bonding involving –OH groups, further confirming the stability of the copolymer backbone [21–22].

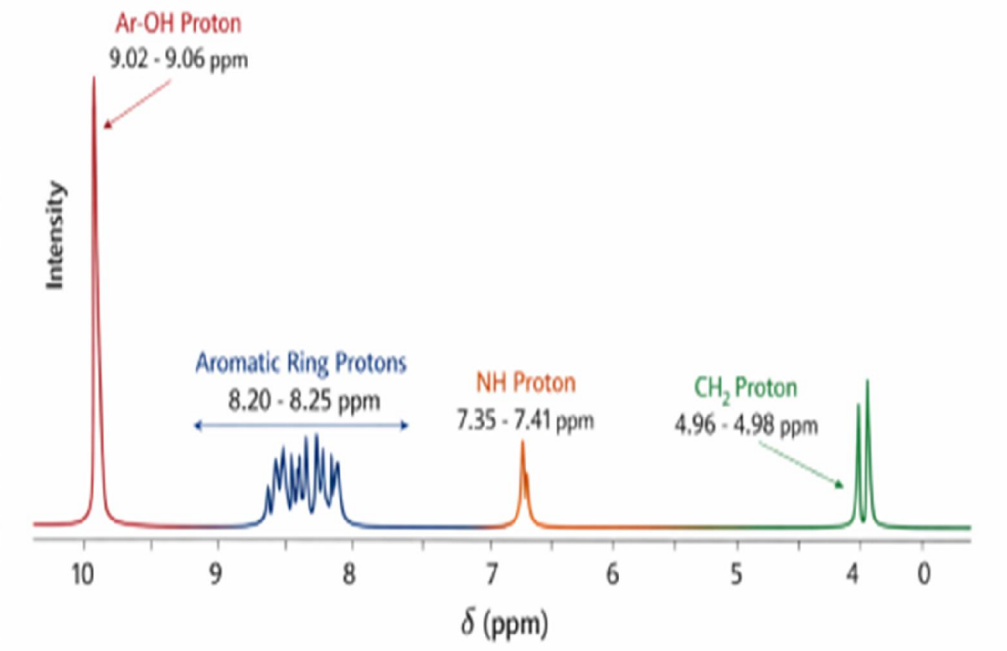

Figure 4: ^{1}H NMR spectrum of 8-HQ5-SAAF-III Copolymer

Table 3: Assigned ^{1}H NMR Signals of 8-HQ5-SAAF-III Copolymer

Proton assigned	Assigned ^{1}H NMR Chemical Shifts for 2, 4-DBAF-III Copolymer
Protons of Aromatic Ring (Appearing as Unsymmetrical Multiplies)	8.20-8.25
Amine Bridging Proton (–NH)	7.35-7.41

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Proton of the –CH□– Group Linking Phenyl and Amine Units	4.96-4.98
Proton of Ar-OH	9.02-9.06

Morphological Analysis of 8-HQ5-SAAF-III Copolymer by Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology of the synthesized 8-HQ5-SAAF-III copolymer (Fig. 5). The micrograph displays the formation of well-defined spherical structures (spherules) with smooth, polycrystalline surfaces, characteristic of a semi-crystalline material [23]. The presence of fringed textures suggests a heterogeneous microstructure comprising both amorphous and crystalline domains, reflecting the influence of acidic monomeric units on the internal organization of the polymer. Densely packed amorphous regions interspersed with deep surface pits may function as active sites for ion-exchange processes, while the appearance of microvoids and surface cracks—likely originating from air entrapment during polymerization or drying—can enhance the effective surface area, favoring adsorption and ion-exchange activity [24]. The observed crystal-like arrangements and extended spherulitic growth further highlight a significant degree of molecular ordering, confirming the semi-crystalline nature of the copolymer and its inherent ability to self-organize during solidification.

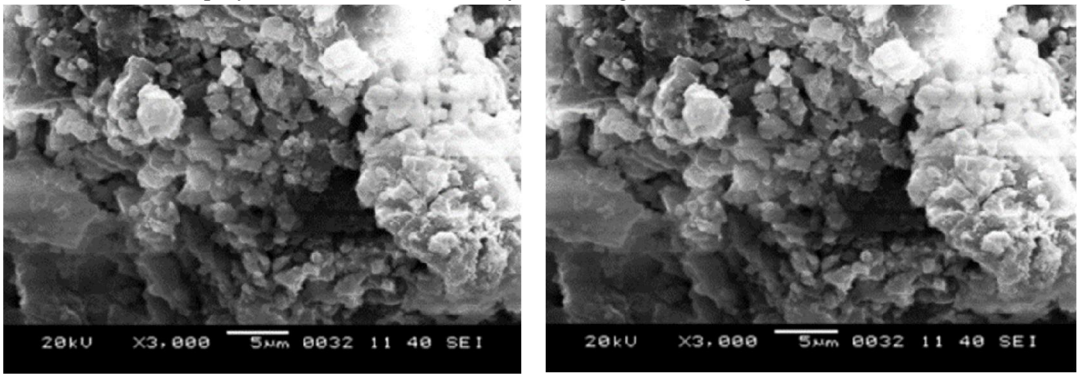

Figure 5: SEM images of 8-HQ5-SAAF-III Copolymer

X-ray Diffraction Analysis of 8-HQ5-SAAF-III Copolymer

The crystalline characteristics of the synthesized 8-HQ5-SAAF-III copolymer were analyzed by X-ray Diffraction (XRD), with the resulting pattern presented in Figure 6. Distinct diffraction peaks observed at 2θ values around 32°, 47°, and 57° confirm the existence of ordered crystalline domains within the polymer matrix. The sharpness and high intensity of these peaks reflect a considerable degree of molecular ordering, underscoring the semi-crystalline nature of the copolymer [25]. Such a well-organized structural arrangement provides critical insights into the physicochemical properties of the material and underscores its potential for advanced applications in separation technologies, adsorption systems, and electroactive devices where crystallinity governs performance.

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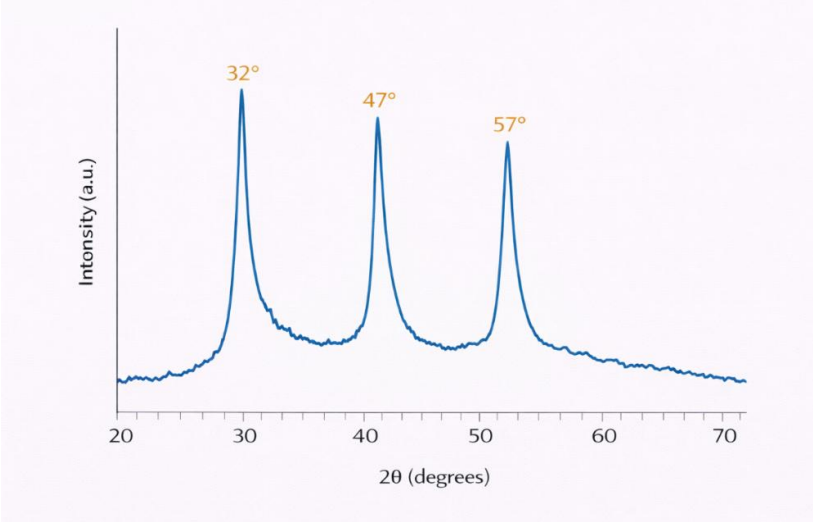

Figure 6: XRD Spectra of 8-HQ5-SAAF-III Copolymer

Thermal Degradation Study of 8-HQ5-SAAF-III Copolymer

The thermal behavior of the 8-HQ5-SAAF-III copolymer was evaluated using thermogravimetric analysis (TGA), with the corresponding thermogram shown in Figure 7. The decomposition profile exhibited a characteristic multi-step degradation pattern. In the initial temperature range of 40–160 °C, a minor weight loss of ~2.01% (experimental) and 2.08% (theoretical) was observed, corresponding to the evaporation of physically adsorbed and crystallization-bound water molecules trapped within the polymer matrix [26]. Subsequent thermal decomposition proceeded through three major steps. The first stage, occurring between 160–290 °C, corresponded to the breakdown of phenolic –OH groups linked to the quinoline units, resulting in a weight loss of 37.12% (experimental) versus 36.98% (calculated). This stage reflects the onset of backbone destabilization, cross-linking, and internal stress relaxation leading to partial fragmentation. The second stage, between 290–520 °C, was marked by a sharp weight loss of 82.95% (experimental) and 83.00% (calculated), [29–30] attributable to decomposition of the $–SO_3H$ group and quinoline aromatic rings, likely through depolymerization, unzipping of cross-linked domains, and thermally induced molecular strain [27–28]. In the final stage (520–800 °C), further weight loss was recorded due to intensified cross-linking and thermal stress, culminating in near-complete degradation of the polymeric framework. This phase accounted for an almost total mass loss of 99.68% (experimental) compared with 100% (theoretical), leaving negligible residual char.These results highlight the excellent thermal degradation efficiency of the copolymer and confirm its complete disintegration under elevated temperature conditions [29-32].

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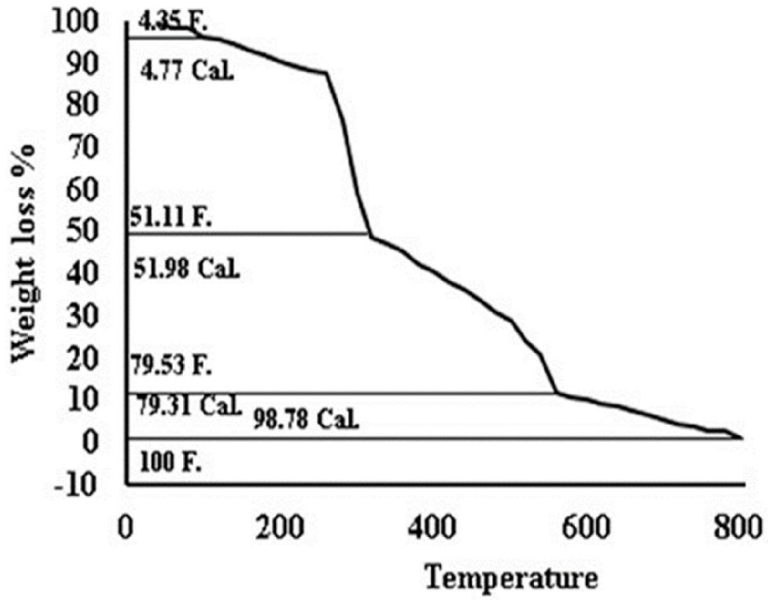

Figure 7. Thermogravimetric curve of 8-HQ5-SAAF-III Copolymer

Evaluation of Activation Energy Using Sharp–Wentworth Approach

The thermal degradation kinetics of the synthesized polymer were analyzed using the Sharp–Wentworth (SW) method, which provides a reliable means of evaluating activation energy (Ea) from thermogravimetric data. This approach involves linearization of the degradation process to extract kinetic parameters with precision [33]. The activation energy was calculated using the following relationship:

$$\text{Log}\left[\frac{\frac{dc}{dt}}{1-c}\right] = \log\left(\frac{A}{\beta}\right)\frac{-Ea}{2.303\,R}\cdot\frac{1}{T} \text{ ------- (11)}$$

Where:

$\frac{dc}{dt}$ = Change in Weight Loss Fraction as a Function of Temperature

C = Degradation extent at time t

B = Linear heating rate

R = Gas constant

T = temperature

A = Frequency factor

Ea = Activation energy (kJ/mol)

A plot of

$$\text{Log}\frac{\left(\frac{dc}{dt}\right)}{1-c} / \frac{1}{T} \text{ ------- (12)}$$

Generate a **straight line** to evaluated the activation energy from the **slope**

$$\text{Slope} = \frac{-Ea}{2.303R} \text{ -------- (13)}$$

This graphical representation (Figure 7) provides a reliable estimation of the activation energy governing the thermal degradation process, thereby offering valuable insights into the kinetic behavior and thermal stability of the copolymer.

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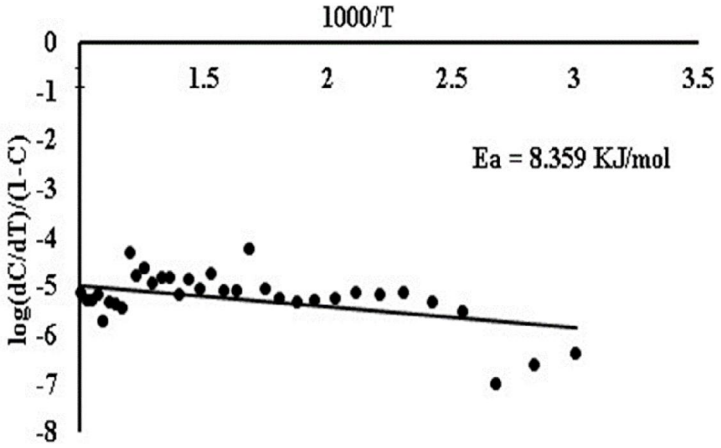

Figure 8. Graphical Determination of Activation Energy via SW Method for 8-HQ5-SAAF-III Copolymer

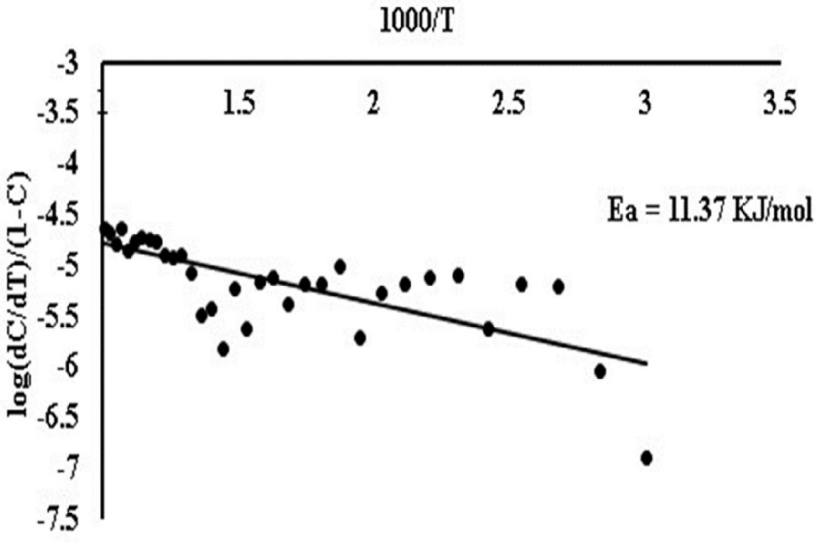

Figure 9. Sharp-Wentworth graph of 8-HQ5-SAAF-III Copolymer

Kinetic Evaluation Using the Freeman–Carroll Method

To further investigate the thermal decomposition behavior of the polymer, the Freeman–Carroll (FC) method was employed to determine both the activation energy (Ea) and the reaction order (n). This method utilizes a differential approach, directly interpreting thermogravimetric data to extract kinetic parameters [34-35]. The calculations were performed using the following mathematical expression:

$$\frac{\Delta \log(\frac{dw}{dt})}{\Delta \log Wr} = \frac{Ea}{2.303R} \cdot \frac{\Delta(\frac{1}{T})}{\Delta Log\, Wr} + n \text{ ---------- (14)}$$

Where:

$\frac{dw}{dt}$ = Mass Accumulation Rate as a Function of Time

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$W_r = W_C - W$

Wc= Decreased Mass Observed Upon Completion of the Reaction

W = Decrease in Sample Mass at a Given Time t

Ea= Activation energy (kJ/mol)

R = Gas constant

T = temperature (K)

n = Reaction rate

The activation energy of the polymer resin was determined by evaluating thermogravimetric data through the application of both the Sharp–Wentworth (SW) method (Figure 9) and the Freeman–Carroll (FC) approach (Figure 10). Values obtained from these two independent approaches were found to be closely aligned, reinforcing the reliability and accuracy of the kinetic parameters associated with the polymer's thermal degradation behavior.

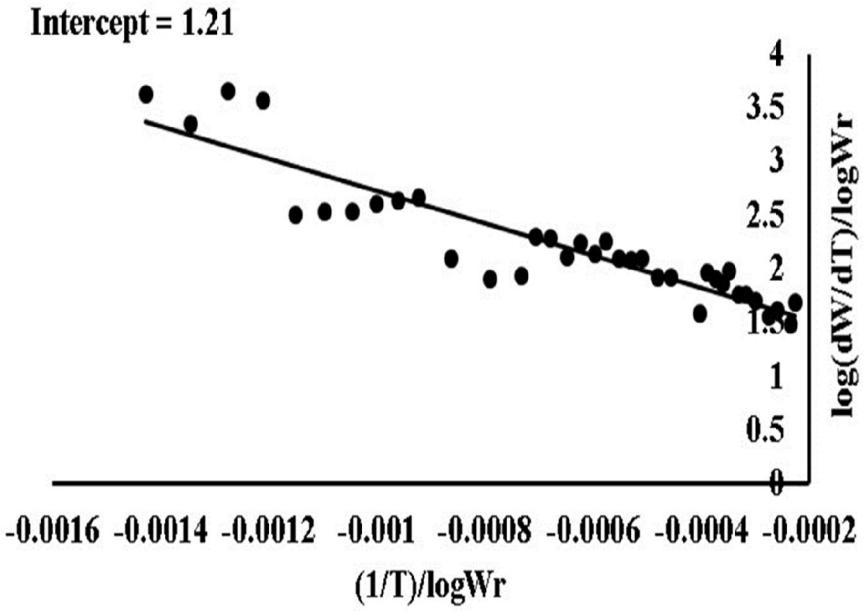

Figure 10. Freeman-Carroll Activation energy graph of 8-HQ5-SAAF-III Copolymer

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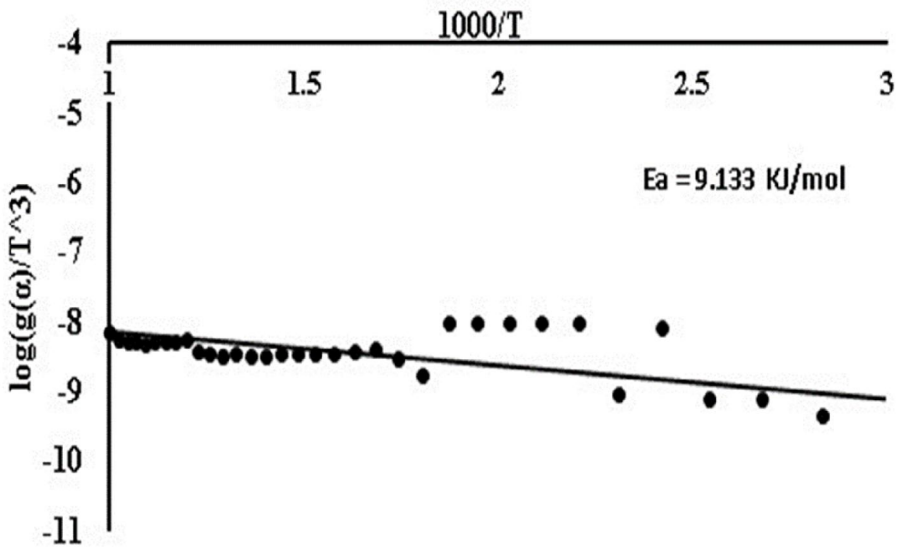

Figure 11. Graphical Analysis of Activation Energy and Reaction Order via FC Method

Table: 5. Study of Kinetic Profiles and Thermodynamic Variables of the Polymer System

Polymer	Activation KJ mol^{-1} (Freeman-Carroll)	Energy[Ea] (Sharp-Wentworth)	Entropy Change (ΔS), (J)	Free energy change(ΔF), KJ	Frequency Factor (Z) Sec^{-1}	Apparent Entropy change (S*)	Order of reaction (n)
8-HQ5-SAAF-III	28.3	28.42	-216.91	113.57	559	-61.33	0.8

The thermal decomposition behavior of the 8-HQ5-SAAF-III Copolymer was further clarified through the evaluation of key thermodynamic parameters, including Gibbs free energy change (ΔF), entropy change (ΔS), apparent entropy (S), and the frequency factor (Z), as presented in Table 6. The activation energy (Ea) values obtained using both the Freeman–Carroll (FC) and Sharp–Wentworth (SW) methods were found to be in close agreement, demonstrating the reliability and consistency of the kinetic analysis. The relatively low frequency factor (Z) suggests that the degradation proceeds via a comparatively slow mechanism, reflecting the inherent thermal stability and molecular framework of the copolymer. Moreover, the negative entropy change (ΔS) signifies that the transition state is more ordered than the initial state, indicating the formation of a highly structured activated complex during the decomposition process.

A comprehensive comparison of the activation energy values for each stage of thermal decomposition, calculated using both the Freeman–Carroll and Sharp–Wentworth methods, is presented in Table 6. The consistency between the two datasets reinforces the validity of the applied kinetic models and provides compelling evidence for the inherent thermal stability of the 8-HQ5-SAAF-III copolymer, confirming its suitability for applications requiring resistance to elevated temperatures.

Table 6: Stages wise Thermal Decomposition of 8-HQ5-SAAF-III copolymer

Polymer	Stages	Temp. variation	Functional group depletion	Weight reduction (%)	Activation (Ea)(KJ/mol) (SW)	Activation (Ea)(KJ/mol) (FC)
8-HQ5-	1^{th}	40.0-150	H_2O	3.29	85.03	25.38

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SAAF-III			molecule entrapped			
8-HQ5-SAAF-III	2nd	150-320	degradation two -OH groups	36.70	28.99	28.39
8-HQ5-SAAF-III	3th	320-480	Reduction of phenyl ring along with two $-CH_2$ groups	59.20	12.18	12.31
8-HQ5-SAAF-III	4th	480-710	Loss of acrylamide moiety.	85.03	86.16	86.02

IV. CONCLUSION

Based on the obtained results, the synthesized 8-HQ5-SAAF-III copolymer, prepared through the condensation of 8-Hydroxyqunoline5-sulphonic acid, acrylamide, and formaldehyde in the presence of an acid catalyst, exhibits robust structural and thermal features. The polymer demonstrated notable thermal stability, with decomposition initiating only at relatively high temperatures, highlighting its suitability for advanced applications requiring resistance to thermal degradation such as high-temperature ion-exchange systems and thermally stable membranes. Furthermore, the comparatively low frequency factor (Z) determined from kinetic analysis indicates that its thermal decomposition follows a slow reaction pathway, an advantageous characteristic for materials expected to retain integrity during extended thermal exposure. Collectively, these attributes position 8-HQ5-SAAF-III as a strong candidate for practical and industrial applications where long-term durability and heat resistance are critical.

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