RESEARCH PAPER

Thermal Decomposition Kinetics of a Copolymer Derived from 8-Hydroxyquinoline-5-sulphonic Acid, Acrylamide, and Formaldehyde

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Abstract

The 8-hydroxyquinoline-5-sulphonic acid, acrylamide, and formaldehyde chemical reactions were sequentially followed to obtain a new copolymer, a multifunctional polymer. The structural properties of the synthesized copolymer were established through the various methods of analysis, such as FTIR spectroscopy, UV-Visible spectroscopy and proton NMR spectroscopy, which confirmed that the functional groups necessary in the main polymer chain were successfully incorporated into the synthesized copolymer. The number-average molecular weight (Mn) and the weight-average molecular weight (Mw) of the copolymer were determined using gel permeation chromatography (GPC). The obtained values revealed that the molecular weight is high with a low polydispersity index (PDI) which showed that the structure of the polymer is uniform and that it can be used in thermally stable polymer matrices. The X-ray diffraction (XRD) analysis has demonstrated that the copolymer was semi-crystalline in nature and scanning electron microscopy (SEM) images indicated a consistent and porous surface morphology. The thermogravimetric analysis (TGA) was used to determine the thermal behavior of the material, and the thermal degradation kinetics were examined by using the Freeman-Carroll and Sharpe-Wentworth methods. The findings proved that the copolymer has high thermal stability. In general, it can be stated that the copolymer synthesized is characterized by high thermal resistance, clear structural and favorable morphological properties, which make it a promising material to employ in sophisticated engineering purposes that demand high thermal resistance and the ability to withstand adverse environment.

Keywords: Copolymerization, Spectroscopy, Surface Characterization, Thermal Characterization, Thermodynamics.

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Introduction

Copolymers consist of two or more different monomers together and are one of the fastest-growing groups of polymeric materials because they offer a lot of possibilities for both design (i.e., structural versatility) and use (i.e., functional versatility). As a result of good molecular design, a variety of different monomers can be incorporated into one single copolymer structure; therefore, a single copolymer structure can contain a number of different properties (e.g., mechanical strength, chemical resistance, ease of processing, thermal stability). Copolymers allow for a wide range of tunability and contribute to improved performance in applications where there are demanding conditions; as such, copolymers will continue to be important in developing new materials and providing improved functionality to existing materials. Some of the areas where copolymers are driving innovation are in the development of coatings, adhesives (high performance), device fabrication in medicine, sustainability, and advanced electronics.

Thermal stability of polymer materials is a very critical parameter that determines the efficiency and stability of the material at high temperatures. Polymers with aromatic rings, cross-linked networks, strong intermolecular bonding tend to resist thermal degradation than polymers that do not have these structural attributes. Due to this, more industries in the aerospace, automotive, electronic, and industrial insulations are taking a keen interest in the development of thermally stable copolymers capable of maintaining their mechanical strength and functional characteristics at elevated temperatures [1- 2].

Gurnule et al. have presented the study of degradation behavior of a thermally stable copolymer obtained by the reaction of 1,5-diaminonaphthalene, 2-hydroxy-4-methoxybenzophenone and formaldehyde at high temperature which gives significant information on the degradation behavior, as well as the degradation mechanism of the copolymer and its thermal stability [3]. A thermally stable copolymer was synthesized in another study by bulk polycondensation of phenylhydrazine, 2, 4-dihydroxy benzoic acid, and formaldehyde in 3:1:5 molar ratio in the presence of an acid catalyst and the findings demonstrated that the copolymer could retain its structural and functional stability at temperatures of thermal stress [46]. Thermal stability and high-performance polymers stability are crucial in the development of polymers that are designed to be used in the advanced technological application [7].

As it was observed by Rathod et al., the thermal stability of a copolymer reduced following the addition of metal ions to the polymer backbone and, therefore, it is possible to conclude that metal coordination has a significant effect on thermal degradation pathway [810]. Rahangdale has conducted a thermogravimetric analysis of the copolymer of 2-hydroxy-4-methoxybenzophenone and 1, 5-diaminonaphthalene and formaldehyde to determine the properties of the copolymer concerning thermal stability [11]. Studies of thermal decomposition of the 2-amino-6-nitrobenzothiazole-oxamide-formaldehyde copolymer revealed that it was more stable thermally because it was able to produce more carbonaceous residue as verified by the TGA results [1213]. The thermogravimetric analysis has found extensive applications in the study of polymers to investigate the behavior of decomposition and thermal resistance, which is useful to learn about the degradation process [14-15].

The current paper is based on the existing literature on thermally stable copolymer, specifically, a new copolymer, 8-hydroxyquinoline-5-sulphonic acid (acrylamide 8-hydroxyquinoline-5-sulphonic)-formaldehyde (8-HQ5-SAAF-II), which was produced using a polycondensation technique. Thermal characteristics of the 8-HQ5-SAAF-II copolymer synthesized were studied by thermal gravimetric analysis and elemental and spectroscopic methods to verify the structural characteristics of the copolymer. The surface morphology was studied with the help of scanning electron microscopy (SEM), and X-ray diffraction (XRD) was performed to understand whether the copolymer is crystalline or amorphous. Also the activation energy and other kinetic and thermodynamic parameters were determined to determine the overall thermal stability of the copolymer.

EXPERIMENTAL

Starting Materials

All compounds and chemicals (acrylamide, dimethyl sulfoxide, N,N-dimethylformamide, hydrochloric acid, and 8-hydroxyquinoline-5-sulfonic acid) used for this research were research-grade chemicals from Central Scientific Company of Nagpur and did not need to undergo further purification.

Synthesis of Copolymer

The synthesis of 8-HQ5-SAAF-II was performed under controlled polycondensation reaction by the use of 8-hydroxyquinoline-5-sulphonic acid, acrylamide and formaldehyde as starting materials with the help of 2 M hydrochloric acid as the catalyst. The mixture of the reaction was left to reflux at 125 o C during 5 hours and this led to the production of a yellow resinous mass. The base polymer was purified with the repeated washing using 8.00 M sodium hydroxide solution and 100.00 M hydrochloric acid solution diethyl ether and distilled water, with the further purification performed through the dissolution process in 8.00 M sodium hydroxide solution as well as the subsequent reprecipitation with the help of concentrated hydrochloric acid and water. The refined product was dried, crushed and sieved to get a homogenous powdered copolymer.

The copolymer was found to be 100% soluble in polar aprotic solvents like DMSO, DMF, and THF, which suggest that it can easily be compatible in organic solvents. Conversely, the polymer was very insoluble in mineral acids and hence there was a small interaction in strongly acidic conditions, which proved the structural stability of the material. The synthesis reaction mechanism of the copolymer 8-HQ5-SAAF-II is shown in Scheme 1.

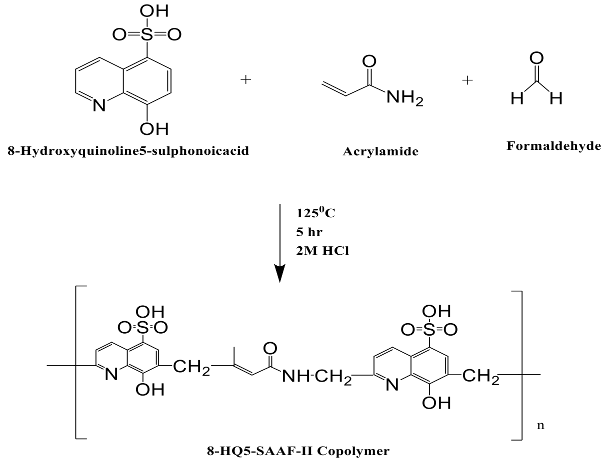

Figure. 1. Configuration and suggested structure of 8-HQ5-SAAF-II copolymer

Instruments

The structural features and chemical composition of the newly synthesized copolymer were examined using several advanced analytical techniques. Elemental composition was determined by elemental analysis with a Perkin Elmer 789N QP-2010 analyzer. The number-average molecular weight, weight-average molecular weight, and molecular weight distribution were measured by gel permeation chromatography (GPC) using tetrahydrofuran (THF) as the mobile phase at a flow rate of 1 mL/min, with calibration performed against polystyrene standards.

Electronic transitions of the copolymer were studied by UV–Visible spectroscopy in dimethyl sulfoxide (DMSO) over the wavelength range of 200–800 nm. Functional groups present in the copolymer were identified using Fourier transform infrared (FTIR) spectroscopy with KBr pellets in the range of 4000–500 cm^{-1}. Further confirmation of the copolymer structure was obtained from proton nuclear magnetic resonance (^{1}H NMR) spectroscopy carried out in DMSO-d$_6$ using a Bruker 400 MHz NMR spectrometer.

Surface morphology of the synthesized copolymer was analyzed using scanning electron microscopy (SEM), while the crystalline nature of the material was examined by X-ray diffraction (XRD). The thermal behavior and degradation kinetics of the copolymer were investigated by thermogravimetric analysis (TGA) using a Perkin Elmer thermogravimetric analyzer.

Physico-chemical characteristics

The standard procedures associated with the determination of vital physicochemical properties of the synthesized copolymer were performed in accordance with the literature, such as the determination of the void volume fraction, solid content, true density, moisture content, and sodium exchange capacity. The obtained measurements were helpful in determining the structural stability and functional performance of the resin which demonstrates that the material can be used in works of separation and purification.

Moisture Content Determination (in %)

The copolymer was also placed in distilled water 0.30 g so that in 46 hours it could be fully wetted so as to ascertain the content of moisture of the material. Then the swollen sample was filtrated and any excess surface water was taken off using filter paper and the wet weight was recorded. The sample was heated in a hot air oven at 90 98 o C during 8 hours and then allowed to cool down at room temperature (30 minutes) and then weighed again. The content of moisture was determined as the percentage difference between the weight of the swollen and the dried sample.

The solid content (%)

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

Where:

W_d = Dried material (g)

W_b = Material before drying (g)

Moisture Content Calculation

The percentage of moisture content was determined using the following equation.

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

True density

$$\text{True density} = \frac{W_p - W}{(W_w - W_{pw}) + (W_p - W_w)} \text{---------------------------} \ (3)$$

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 copolymer's fundamental physical characteristics, including solid and water content; true density; and bulk density were evaluated using established literature procedures while also enforcing consistency across methodologies was done by following systematic controls for implementing these protocols.

Thermal analysis

Thermal stability and stepwise degradation behavior of the synthesized copolymer were examined by thermogravimetric analysis (TGA) that gave a detailed profile of the decomposition behavior at a controlled temperature. Based on the TGA results, some key kinetic and thermodynamic parameters had been obtained to gain a better insight into the thermal performance of the copolymer. Two widely known non-isothermal kinetic techniques, which are the FreemanCarroll (FC) model and the SharpWentworth (SW) model, were applied to perform the analysis. Comparison of the results obtained using both techniques proved that the copolymer has a good thermal resistance and the material can be used in any application which requires high thermal stability.

RESULTS & DISCUSSION

Elemental Analysis of 8-HQ5-SAAF-II copolymer

The synthesized 8HQ5-SAAF-II copolymer was characterized through microanalytical analysis of its elemental composition, i.e. in terms of carbon, hydrogen, nitrogen, and sulfur. The findings verified the stoichiometry and integrity of the copolymer structure, since the experimented elemental percentages were close to the theoretical ones. According to these results, the empirical formula of the copolymer was determined that made it possible to determine the molecular weight of repeating unit. Table 1 shows both theoretical and experimental data that were employed to measure the structural consistency of the copolymer.

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-II	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 Characterization of 8-HQ5-SAAF-II copolymer

Gel permeation chromatography (GPC) is a method of measuring the distribution of molecular weight of a polymer by subjecting the polymer chains to diffusion based on hydrodynamic volume in an appropriate solvent which makes it possible to estimate the chain length and molecular weight. Tetrahydrofuran (THF), with a flow rate of 1 mL/min., was used as the mobile phase in this experiment to have a stable calibration curve by the use of known polystyrene samples of molecular weight. The molecular weight and parameters associated with it such as the number average molecular weight (Mn) are given in Table 2 and it gives information on the molecular structure and distribution profile of the synthesized copolymer.

Table 2: Molecular Weight determination of 8-HQ5-SAAF-II copolymer

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

Spectral studies

UV–Visible Spectroscopic Analysis of 8-HQ5-SAAF-II copolymer

The UV-Visible absorption spectrum of 8-HQ5-SAAF-II copolymer was taken in pure DMSO as the solvent, and it is given in Fig. 2. It was measured using the wavelength of 200-850nm and scanning at a rate of 100nm/min. Two high absorption bands were noticed. The former band was observed at the range of 360370 nm, and the latter was at the range 240260 nm.

The higher wavelength band of absorption is attributed to the π- π electronic transitions of the aromatic ring system but the lower wavelength band is related to the n - 0 transitions of the functional groups of -OH and -NH that exist in the side chains of the copolymer. Hypochromic shift also took place implying that the -OH and -NH groups are auxochromes and affect the intensity of light absorption [16].

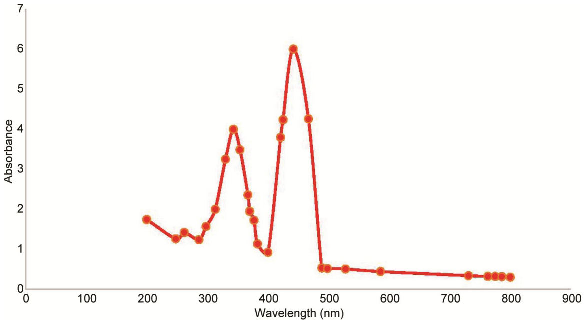

Figure 2. Ultraviolet–Visible Absorption Spectrum of 8-HQ5-SAAF-II copolymer

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

The synthesized copolymer was found to have structural characteristics which were confirmed by its FTIR spectrum (see Fig. 5, Table 4) as shown by the absorption bands identified in the table. The wide absorption band at the range of 35063508 cm -1 represents the OH stretching frequencies of the phenol hydroxyl groups and indicates the existence of intramolecular hydrogen bonding between the hydroxyl groups [17]. The absorption band at 15561626 cm -1 gives a strong and sharp band, suggesting the presence of aromatic skeletal vibrations, and the absorption band at 12101230 cm -1 is evidence of the existence of methylene (-CH 2) bridge linkages [18].

Bands at medium to low intensity observed at 9531046114511821188 -13201321 -1 are designated to benzene ring 1,2,3,5 substitution. The band at 3393 3402 cm minus phenylalanine was also found to be at 3393 3402 cm minus the phenylalanine band, and this indicates the presence of both phenolic and amino functional groups in the polymer backbone.

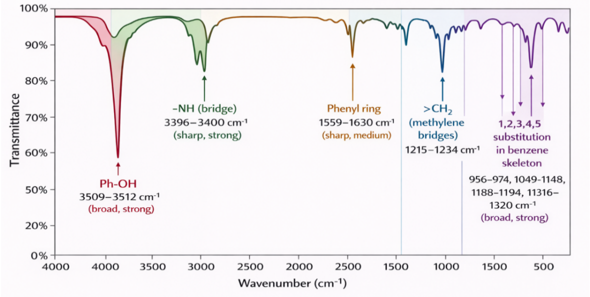

Figure 3: FTIR Spectroscopic Characterization of 8-HQ5-SAAF-II copolymer

Table 2: FT- IR spectral data of 8-HQ5-SAAF-II 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)
>CH₂ (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-II copolymer

The Copolymer Known to be Synthesized 8-HQ5-SAAF-II Was Characterized via H NMR of the Copolymer in DMSO-d6 Were Observed, Based on Interpreted Spectral Assignments for Copolymer Analogues as Reported in Literature[19,20]. There Was A Singly-Displaced Peak Between δ4.96 to 4.98 ppm Corresponding to the Methylene Of The methylene Protons Nearby The Ph-CH2-N Group. Between δ7.35 to 7.41 ppm, We Observed Chemical Shifts Due to The Protons of the Bridge Groups (NH), Which Also Had Chemical Shifts Of The -NH To The Bridging Protons. Between δ8.20 to 8.25 ppm, That We Observed Chemical Shifts of The Ar-H Protons Were Very Asymmetrical with Their Corresponding -NH and Phenolic -OH Peaks Emitted At δ9.02 to 9.06 ppm. Intramolecular hydrogen bonding was suggested by the significant downfield displacement from the -OH Peaks. This Suggests Stable copolymer structure.[21,22].

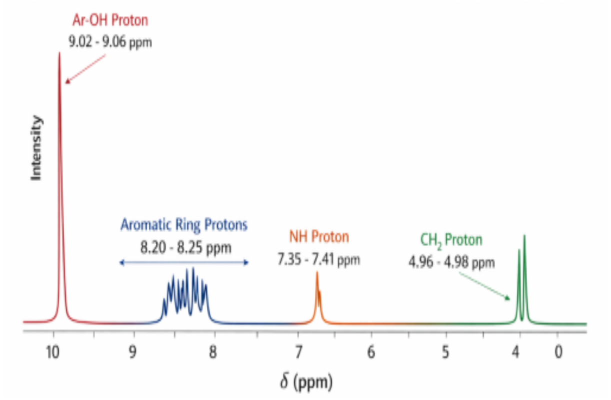

Figure 4: ^{1}H NMR Characterization of 8-HQ5-SAAF-II copolymer

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

Proton assigned
Protons of Aromatic Ring (Appearing as Unsymmetrical Multiplies)
Amine Bridging Proton (–NH)
Proton of the –CH_2– Group Linking Phenyl and Amine Units
Proton of Ar-OH

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

Surface morphology of 8-HQ5-SAAF-II copolymer was studied by scanning electron microscopy (SEM) (Fig. 5). The micrograph showed distinct spherical shapes (spherules) with comparatively smooth polycrystalline faces which are characteristic characteristics of semi-crystalline materials [23]. The existence of fringes with a texture implies that there might be a heterogeneous microstructure composed of polycrystalline and amorphous zones, which might be affected by the acidic monomer units in the organization of the inside of the copolymer.

It is anticipated that the densely packed amorphous regions with notable surface pits will offer active sites in the ion-exchange, and the presence of microvoids and small cracks during the polymerization and drying of the product will augment the effective surface area and raise adsorption and ion-exchange characteristics [24]. The crystalline-like structure present along with the elongated growth of the spherulitic structure demonstrates a rather high level of structural order within the copolymer, which proves the semi-crystalline structure and its predisposition to structure during the solidification process.

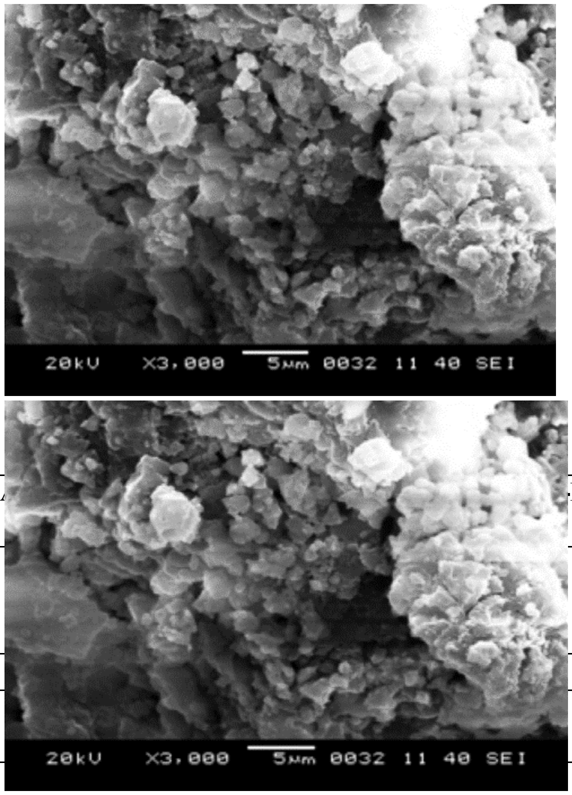

Figure 5: SEM images of 8-HQ5-SAAF-II Copolymer

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

X-ray diffraction (XRD) was used to determine the crystalline nature of the 8-HQ5-SAAF-II copolymer and the diffraction pattern was obtained as indicated by Fig. 6. The emergence of distinct diffraction peaks at approximately 32, 47 and 57 (2)-degrees, provides the evidence of the existence of ordered crystalline domains in the framework of the polymer. These sharp and sharp peaks are the evidence of a high level of molecular ordering, which proves the semi-crystalline nature of the copolymer [25].

This type of structured system can be useful in understanding the physicochemical characteristics of the material and indicate that the copolymer can be used in more sophisticated applications such as separation processes, adsorption systems, and electroactive devices, the existence of crystalline domains of the material being a significant factor in performance.

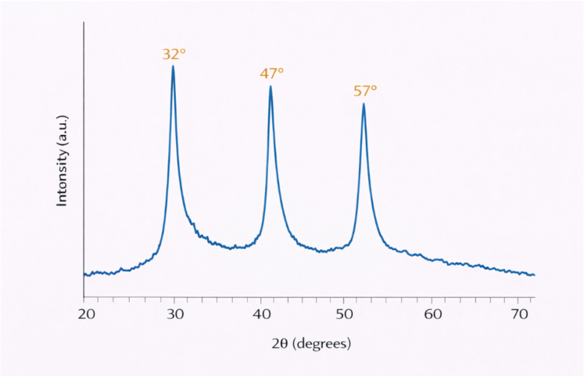

Figure 6: XRD Spectra of 8-HQ5-SAAF-II Copolymer

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

The thermal properties of the 8-HQ5-SAAF-II copolymer were studied by thermogravimetric analysis (TGA), and the thermogram was depicted in Fig. 7. The degradation process is typical with a multi-step decomposition process. In the low temperature (40-160 C) range, the percentage of weight loss was very low (approximately 2.01 percent experimentally and 2.08 theoretically) and this is because the physically adsorbed or crystallization bound water molecules within the polymer matrix were removed. Thermal decomposition to this stage was followed by three major steps. The initial decomposition phase (160 290 C) is linked to the loss of the phenolic -OH group on the quinoline units as well as the removal of bound water molecules with an 37.12% (experimental) versus 36.98% (calculated) weight loss. This step is an indication of the onset of structural destabilization, release of internal stress, and partial destruction of polymer net.

The second cycle (290-520 o C) exhibited the swift reduction of the weight whereby 82.95 percent of the experimental weight loss was observed as compared to 83.00 percent theoretical weight loss [29-30]. This is primarily because the-SO 3H groups were broken down as well as the disintegration of quinoline aromatic rings by means of depolymerization, splitting of cross-linked areas, and strain creation in the polymer structure with the help of heat [27-28]. During the third stage (520800 - 1 C), the polymer underwent additional fast degradation because of the enhanced cross-link breakages and thermal stress leading to the nearly total disintegration of the polymer framework. The result of this step was a total weight loss of 99.68 percent (experimental) against 100 percent (theoretical), with nearly no char remaining. On the whole, the findings show that the copolymer has an effective stepwise thermal degradation and is capable of fully degrading at high temperatures, and hence it has a clearly defined thermal degradation pattern [29-32].

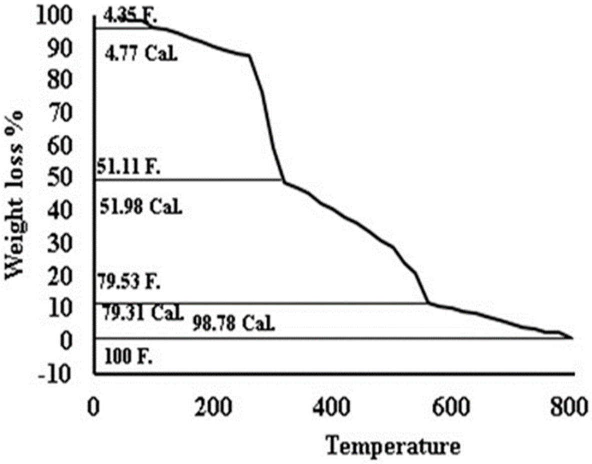

Figure 7. Thermogravimetric curve of 8-HQ5-SAAF-II Copolymer

Evaluation of Activation Energy Using Sharp–Wentworth Approach

The polymer synthesized was analyzed by means of the Sharp-Wentworth (SW) method, which, as previously described in the literature, is a valid way to calculate activation energy (EA) through thermogravimetric data. Linearization of the degradation process allows for accurate extraction of kinetic parameters from a thermogravimetric analysis [33]. The activation energy, which is denoted by the following expression, was calculated using the approach described follows:

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

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

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

Generate a straight-line plot in order to evaluate the activation energy from the slope of the graph.

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

According to the data shown in Figure 7, the activation energy for the thermal degradation of the copolymer can be estimated, which allows evaluation of the kinetic behavior and thermal stability of the material.

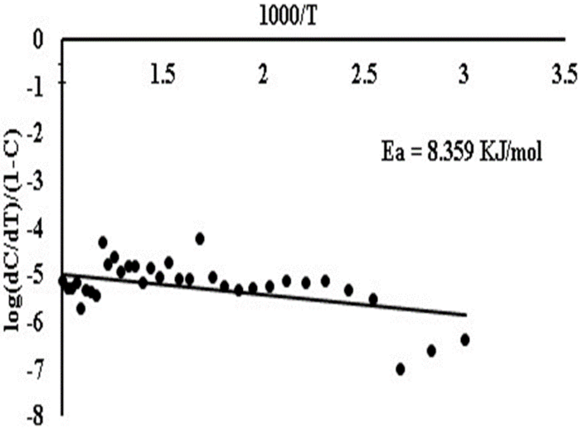

Figure 8. Graphical determination of activation energy using the Sharp–Wentworth (SW) method for the 8-HQ5-SAAF-II copolymer.

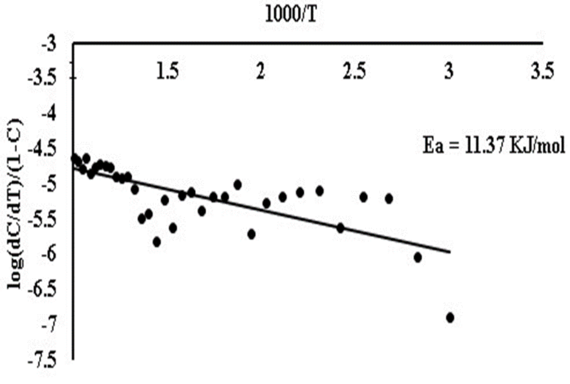

Figure 9. Sharp–Wentworth plot for the 8-HQ5-SAAF-II copolymer

Kinetic evaluation using the Freeman–Carroll method

A dynamic study of the thermal decomposition mechanism of the polymeric sample has been carried out using the FC method, whereby the kinetic parameters (activation energy and reaction order) were calculated by thermogravimetry (via differential interpretation) for the poly (vinyl chloride) sample using the equations:

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

Where:

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

$W_r = W_C - W$

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 thermogravimetric data was used in both the Sharp-Wentworth (SW) and Freeman-Carroll (FC) techniques to find the activation energy of the polymer resin (Figures 9 and 10). The results of the two methods produced very similar values of the activation energy, which proves that the two methods were able to record the actual kinetic phenomena of the polymer and can be regarded as valid.

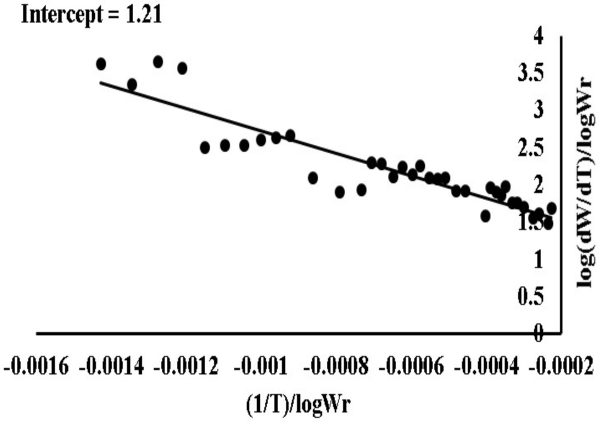

Figure 10. Freeman–Carroll activation energy plot for the 8-HQ5-SAAF-II copolymer.

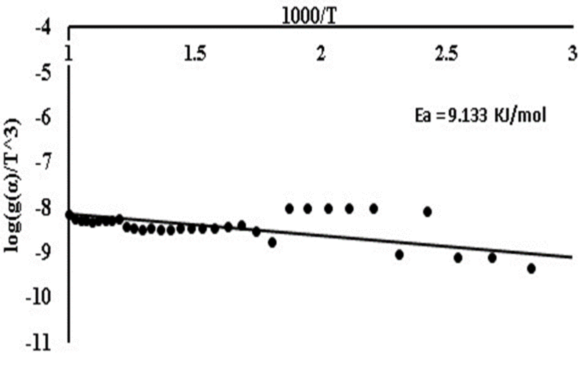

Figure 11. Graphical analysis of

activation energy and reaction order using the Freeman–Carroll (FC) method.

Table: 5. Study of kinetic parameters and thermodynamic properties 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-II	26.3	28.42	-216.91	113.57	559	-61.33	0.8

Further analysis of the thermal degradation behavior of the 8-HQ5-SAAF-II copolymer was done by computing key thermodynamic quantities that are related to the decomposition process, such as Gibbs free energy change (ΔF), entropy change (ΔS), apparent entropy (S) and frequency factor (Z). The table 6 gave the values in the activation energy (Ea) which were obtained by both the Freeman-Carroll (FC) and Sharp-Wentworth (SW) methods. Activation energies derived using the two methods have a close agreement meaning that the kinetic analysis is accurate and reliable.

The small value of the frequency factor (Z) indicates that the thermal degradation of the copolymer occurs via a relatively slow process, which justifies the existence of good inherent thermal stability that is due to the strong molecular structure of the polymer. A negative value of ΔS refers to the fact that a transition state is more organized than the initial one, which means that a highly organized activated complex is formed in the degradation process.

The comparison between the activation energy values of the first (1 0) and the second (2 0) stage of the thermal degradation calculated using the FC and the SW methods are also presented in Table 6. It was seen that the values of the two methods are very close, which proves the validity of the applied kinetic models and also indicates the high thermal stability of the 8-HQ5-SAAF-II copolymer, which should be used in high temperature application.

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

Polymer	Stages	Temp. variation	Functional group depletion	Weight reduction (%)	Activation (Ea)(KJ/mol) (SW)	Activation (Ea)(KJ/mol) (FC)
8-HQ5-SAAF-II	1th	40.0-150	H_2O molecule entrapped	3.29	85.03	25.38
8-HQ5-SAAF-II	2nd	150-320	degradation two -OH groups	36.70	28.99	28.39
8-HQ5-SAAF-II	3th	320-480	Reduction of phenyl ring along with two -CH_2 groups	59.20	12.18	12.31
8-HQ5-SAAF-II	4th	480-710	Loss of acrylamide moiety.	85.03	86.16	86.02

Conclusion

Recent researches have shown that this copolymer (8-hydroxyquinoline-5-sulphonic acid–acrylamide–formaldehyde) has great structural and thermal characteristics. The resulting polymer is thermally stable, and it takes a long time to decompose, which proves that the polymer meets the demands of high-tech applications under high thermal conditions, including the high-temperature ion-exchange systems and thermally stable membrane materials.The fact that the frequency factor (Z) calculated with the help of the kinetic analysis is relatively small also indicates the fact that the degradation process occurs at a low reaction rate in terms of thermal degradation, which means that the polymer can preserve its structural integrity even in case of the high-temperature exposure. The latter attributes suggest that 8-HQ5-SAAF-II is an appropriate material that can be applied into a practical scenario that requires high-levels of long-term durability and heat resistance.

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