Available online at www.elixirpublishers.com (Elixir International Journal)

Applied Chemistry

Elixir Appl. Chem. 48 (2012) 9557-9562

ISSN: 2229-712X

Thermal degradation and electrical conductivity measurement study of resin derived from salicylic acid, hexamethylenediamine and formaldehyde

Dhanraj.T.Masram[1], K.P.Kariya[2] and N.S.Bhave[3]

[1]Department of Chemistry, University of Delhi, Delhi-110007, India.

[2]Department of Chemistry, VMV commerce JMT Arts & JJP Science College, Nagpur-440008.

[3]Department of Chemistry, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur-440033.

ARTICLE INFO

Article history:

Received: 23 May 2012;

Received in revised form:

28 June 2012;

Accepted: 23 July 2012;

Keywords

Resin,

Polymer synthesis,

Thermal properties,

Activation energy,

Electrical conductivity.

ABSTRACT

The resin SHMF has been synthesized by the condensation of salicylicacid and hexamethylenediamine with formaldehyde and hydrochloric acid as catalyst. Thermal degradation curve has been discussed which shows four decomposition steps and detailed thermal degradation studies of the resin have been carried out to ascertain its thermal stability. Sharp–Wentworth and Freeman–Carroll methods have been used to calculate activation energies and thermal stability. The activation energy (Ea) calculated by using the Sharp–Wentworth (17.86 kJ/mol) has been found to be in good agreement with that calculated by Freeman–Carroll (18.96 kJ/mol) method. Thermodynamic parameters such as free energy change (ΔF), entropy change (ΔS), apparent entropy change (S*) and frequency factor (Z) have also been evaluated on the basis of the data of Freeman–Carroll method. The order of reaction (n) is found out to be 0.99. Electrical conductivity measurements have been also conceded to ascertain the semiconducting nature of the resin.

Introduction

The resins offer novelty and versatility; hence they occupy the pivotal position in the field of material science. The progress in the field resins has been extremely rapid, as they generally useful in packaging, adhesives and coatings in electrical sensors and organometallic semiconductors [1-4]. Phenolic resins have a large number of practical applications in electronic controls, insulating materials, protective adhesives, aerospace industries etc. because of their high thermal stability, heat and chemical resistance and electrical insulation properties [5-7].Various researchers have been studied the applications of resins of substituted phenols and formaldehyde [8-10]. 2-Hydroxyacetophenone and its substituted derivatives have been condensed with formaldehyde to produce heat and light stabilizers. Resins of salicylic acid, thiourea with trioxane and p-hydroxybenzoic acid, thiourea with trioxane have been reported in the literature [11-14]. Manavalan and Patel [15] synthesized resins of salicylic acid, urea and formaldehyde and also studied the various properties of resins.

Semiconductors are the most important ingredients of modern electronics. The concerted research effort was carried out to aim at developing an organic material that would posses the good electrical properties as the inorganic semiconductors. In the early days the prime attention was placed on the synthesis of highly conductive polymers, preferably of high molecular weight and the measurement of their electronic conductivity properties i.e. conductivity, mobility, thermoelectronic power, etc. The resins are well known for their behavior as semiconductors though carrier mobility in them usually is very low [16-18]. Kand a et al reported the rubeanato –copper semiconductive polymers and studied their AC and DC conductivity [19]. Dhawan and coworkers reported the conducting polymers predicted to be the futuristic materials for the development of light emitting diodes, antistatic and EMI materials, sensors, opto- electronic devices and rechargeable batteries due to their unique conduction mechanism and greater environmental stability [20].

In our laboratory we study on the synthesis of materials for high thermal stability and electrical conductivity measurements of resins derived from salicylicacid / p-hydroxybenzoicacid, diamide / urea / thiourea with formaldehyde [6,7, 12-14,21-24]. Our previous paper [21] describes the synthesis and characterization of SHMF resin. The present communication deals with thermal degradation and electrical conductivity properties of a newly synthesized resin derived from salicylicacid, hexamethylenediamine and formaldehyde.

Methods for the estimation of kinetic parameters from thermo gravimetric studies are generally based on the assumption that the Arrhenius equation is valid with thermal and diffusion barriers are negligible. After treating the thermal degradation data with Sharp–Wentworth (SW) and Freeman–Carroll (FC) methods, activation energy and kinetic parameters such as ΔF, ΔS, Z, S* and n (order of reaction) have been evaluated [25-27]. For the electrical conductivity measurement study the DC resistivity of the SHMF resin have been measured by applying a constant voltage (50 volts) across the pellets. The temperature dependence of the electrical conductivity of the resin has been plotted. The energy of activation (E_a) of electrical conduction is calculated from the slope of the plots. Electrical conductivity of the resin has been studied with increase in temperature.

Experimental

Chemicals

All Chemicals were AR grade. Salicylicacid, hexamethylenediamine and formaldehyde were purchased from

Tele:

E-mail addresses: dhanraj_masram27@rediffmail.com

Aldrich Chemical Co., USA. DMF and DMSO were used as solvent of HPLC grade.

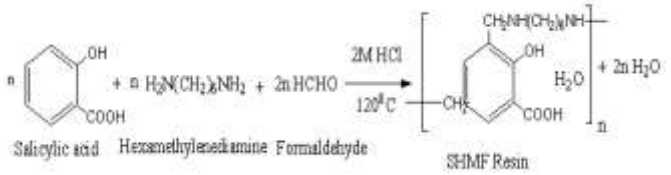
Instruments Used

Thermogravimetric analyses (TGA) of resin sample has been carried out by using Perkins Elmer TGS-ll thermal analyzer at heating rate of 10^0C per minute and in air atmosphere upto 800^0C. The thermogram was recorded at Sophisticated Instrumentation Centre for Applied Research and Testing (SICART), Vallabh Vidyanagar, Gujrat.

The electrical resistivity of the resin was measured with help of Hewlett-Packard 4192 Impendance Analyser 5Hz-13MHz at Department of Physics, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur over a wide range of temperature i.e. from 313-423 K.

Synthesis and Characterization of SHMF Resin

A mixture of salicylicacid, hexamethylenediamine and formaldehyde was taken in the ratio of 1: 1: 2 with 2 mol–L^{-1} hydrochloricacid as catalyst in a round bottom flask. The flask was fitted with water condenser and heated in an oil bath at 120^0C for 7 hours with occasional shaking. The resinous solid product obtained was immediately removed from the flask as soon as the reaction period was over and then purified. The resinous product so obtained was repeatedly washed with cold distilled water dried in air and powdered with the help of agated mortar and pestle. The powder was washed many times with hot water to remove unreacted monomers. The air-dried powder was extracted with diethyl ether and followed by washing with the petroleum ether to remove salicylicacid - hexamethylenediamine copolymer, which might be present along with SHMF resin.Our paper [21] reveals the characterization of resin by elemental analysis, infrared (IR) spectroscopy, nuclear magnetic resonance (NMR) spectroscopy and UV- Visible spectral studies. The number average molecular weight of the resin was determined by non-aqueous conductometric titration.



Scheme: Synthesis of SHMF Resin

Thermogravimetry

Thermal analysis method is associated with a change in weight with respect to temperature. Heating is performed under strictly controlled conditions and can reveal changes in structure and other important properties of the material being studied. In non-isothermal or dynamic TGA the sample is subjected to conditions increase in temperature at linear rate [28, 29].

The Freeman – Carroll and Sharp- Wentworth methods have been employed for the calculation of kinetic parameters of the newly synthesized resin with help of dynamic TG curve [6,12,14,22-24, 27]. The advantage of Freeman and Carroll method that in one single stage by keeping heating rate constant both the order of reaction and energy of activation can calculated in a single experiment. The following expression is used to evaluate various kinetic parameters:

$$\frac{\Delta \log dw/dt}{\Delta \log Wr} = n - \frac{Ea}{2.303R}.\frac{\Delta(1/T)}{\Delta \log Wr}$$

Hence, a plot of $\frac{\Delta \log\left(\frac{dw}{dt}\right)}{\Delta \log W_r}$ vs. $\frac{\Delta(1/T)}{\Delta \log W_r}$ should give a straight line with an intercept on y-axis equal to the value of n (the order of reaction) and the slope m = E / 2.303R.

Where, dw/dt is the rate of change of weight with time and in expression Wr = Wc –w,

W_c is the weight loss at the completion of the reaction, w is the total weight loss upto the time t and T is the temperature in k.

The following expression is used to evaluate Ea with Sharp-Wentworth method:

$$\log \frac{(dc/dT)}{(1-c)} = \log(A/\beta) - \left[\frac{E_a}{2.303R}\right].\frac{1}{T}$$

Where, dc/dt is the rate of change of mass with time t, T is the temperature and $\beta = \Delta T/dt$.

Electrical conductivity

The resins are well known for their behavior as semiconductors though carrier mobility in them usually is very low. This is due to the difficulty which electrons experience in jumping from one molecule to another and so the carrier mobility in compounds of these kind increases with increase in molecular size [16-20].The measurements involved following steps.

Preparation of pellets for Resistance Measurements

Resin was dried and thoroughly ground in agate pestle and mortar to palatalized isostatically in a steel die at 10 tones/2inch with the help of hydraulic press. A thin layer of colloidal graphite in acetone was applied on both sides of the pellets and dried at room temperature for 4-6 hr. The colloidal graphite on either side of pellets functioned as electrode. The surface continuity of pellet was then tested by means of mutlimeter. The average diameter of this pellets and its thickness were measured using Screw Gauze. Actual dimensions were measured as average of the three measurements taken at three places.

Sample Holder

A typical sample holder was designed for the purpose of resistivity measurement. A simple spring loaded sample holder was fabricated using silver electrodes with alumina base. The prepared pellet was mounted between the two silver electrodes, one of which was spring loaded while other electrode rested on the alumina base platform which presses hard against the surface of the pallet.

Furnace for Heating Sample

For measurement of resistivity at different temperature, a suitable electrical furnace was used. Heating of furnace was controlled with the help of dimmerstat. The current to the furnace was recorded by means of AC ammeter. The accurate measurement of the temperature of the furnace was achieved by means of slandered chromel-alumel thermocouple connected with systronic digital multimeter in which the e.m.f developed in milivolts was measured. The measuring junction of the thermocouple and the pallet in the sample holder were at the same level, almost in the center of the furnace where temperature was uniform. The connecting wires of the two electrodes were insulated with porcelain beads, and were taken out for connections.

Measurement of Resistivity

Hewlett-Packard 4192 Impendance Analyser 5Hz-13MHz was used to measure the electrical conductivity of all resin. The temperature variations of resin were studied by placing the sample holder along with the pallet in the electric furnace and were then heated slowly. The slow rate of heating 1 to 10 ^{0}C per minute was maintained throughout the investigation. Connection wires from the furnace were connected to the terminals of the instrument. The resistances of the sample pallets were measured by two probes (terminals) method.

Resistivity (ρ) was then calculated using the relation:

$$\rho = R. x A/l$$

Where, R= resistance of the pellet.
A = Surface area of pellets and
l = Thickness of pellet.

The DC resistivities were measured from 313 to 423 K. The electrical conductivity (σ) varies exponentially with the absolute temperature according to the well-known relationship.

$$\sigma = \sigma_0 \exp^{-Ea/kT}$$

Where, σ =electrical conductivity at room temperature (T)
σ_0 =electrical conductivity at temperature constant
Ea =Activation energy of electrical conduction.
K= Boltazmann constant (1.3817x10-23 J molecule^{-1}k^{-1})
T= Absolute temperature
The relationship has been modified as

$$\text{Log } \sigma = \log\sigma_0 + \text{ -Ea/2.303kT}$$

According to this relation, a plot of Log σ Vs 1/T would be linear with negative slope. From the Slope of the plots, the activation energy was calculated [16-20, 31].

Results and discussion

Thermal Degradation Study for SHMF Resin

The thermal degradation curve for SHMF resin is shown in Figure1 exhibits four-stage decomposition and its ranges are given in Table 1.The first stage decomposition which was slow and ranged from 40-160 ^{o}C corresponding to loss 6.3% which may have been due to entrapped H_2O molecule. The second stage decomposition represents degradation of side chain attached to aromatic nucleus. [Observed 57.9% against calculated 57.6%].The third stage decomposition at 240-420 ^{o}C which may be due to the loss of phenolic -OH and –COOH groups [observed 64.9% and calculated 65.54%]. The fourth state decomposition is probably total decomposition of resin. The Half Decomposition temperature for SHMF resin is found to be 225^{o}C.

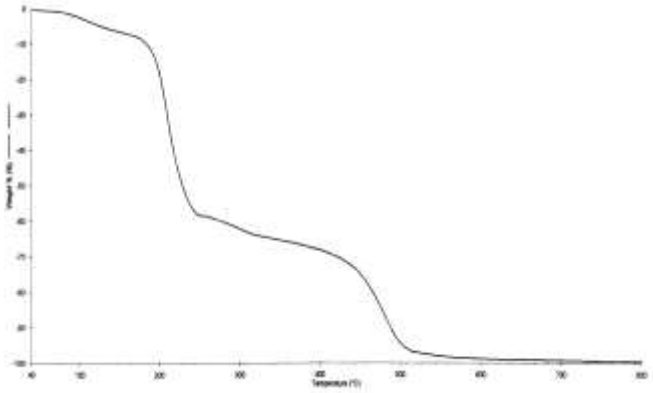


Fig.1: Thermogram of SHMF resin

A representative thermal activation energy plot [Figure -2] and Freeman-Carroll plot [Figure –3] for the polymer has been shown. By using thermal decomposition data and then applying the Sharp-Wentworth method [shown in Figure - 4] activation energy has been calculated which is in agreement with the activation energy calculated by Freeman-Carroll method. The thermodynamic parameters have been calculated on the basis of thermal activation energy. These values are incorporated in [Table - 2].

Due to abnormally low value of frequency factor [Z] it may be classified as a slow reaction and no other obvious reason can be given. The value of entropy [ΔS] indicates that the activated polymer has more ordered structure than the reactants and the reaction are slower than normal. This is further supported by low Z values [22- 24, 28, 29].It is very difficult to draw any unique conclusion from the magnitude of thermal activation energy [Ea] as decomposition mechanism is expected to be complicated. Positive values of activation energy under present investigation correspond to the energy of activation due oxidation–reduction process of resin in the higher temperature range [22- 24, 28, 29].

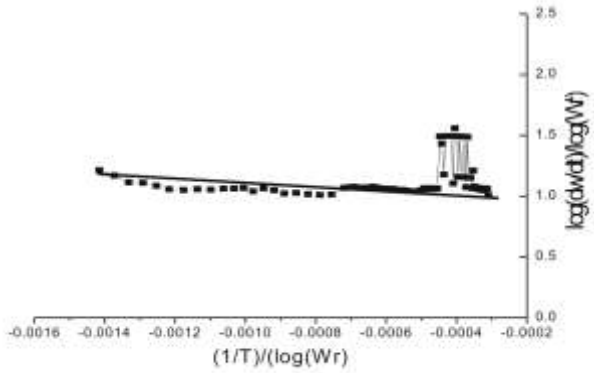


Fig .2: Thermal Activation Energy Plot of SHMF Resin

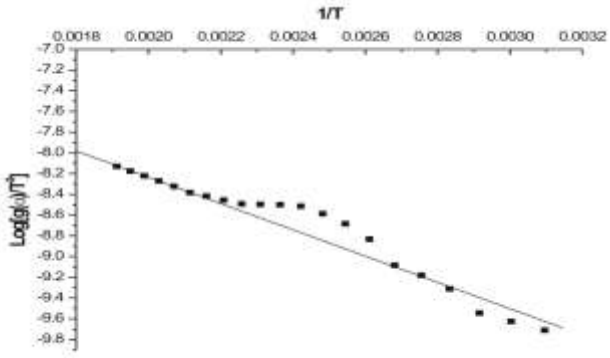


Fig .3: Freeman – Carroll Plot of SHMF Resin

Fairly straight line plots are obtained using the two methods. However, using the Freeman- Carroll method some abnormal points were ignored to get a clear picture about most of the points. Similarly, in the Sharp- Wentworth method, some points at the beginning or the end did not fall on straight line. This is expected, since, the decomposition of resin is not obeying first order kinetics perfectly. These observations are in harmony with the findings of Jacobs and Tompkin and other earlier workers [30].

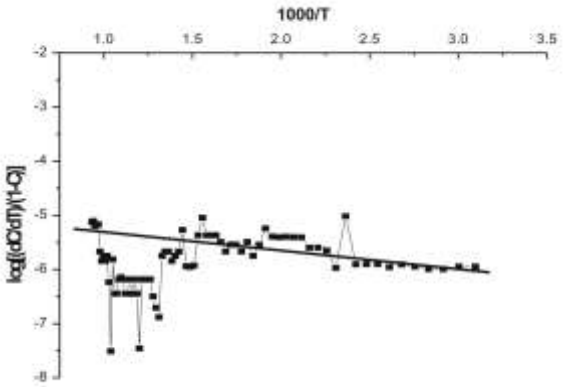


Fig .4: Sharp-Wentworth Plot of SHMF Resin

Electrical Conductivity for SHMF Resin

The results of electrical conductivity and activation energy are incorporated in Table 3. The temperature dependence of the electrical conductivity of the resin has been mentioned in

Figure.5. The electrical conduction of polymeric material depends upon incalculable parameters such as porosity, pressure, method of preparation, atmosphere etc; activation energy (Ea) is not affected by these parameters and, therefore, it is fairly reproducible [31-35]. The magnitude of activation energy depends on the number of electrons present in semiconductor materials. The more the number of Л – electrons lowers the magnitude of activation energy and vice versa. Generally polymers containing aromatic nuclei in the backbone exhibit lower activation energy than those with aliphatic system. Thus, the low magnitude of activation energy may be due to the presence of large number of Л-electrons in the polymer chain. This is in good agreement with the most probable structure proposed for the newly synthesized resin under investigation [16-20, 31-35].

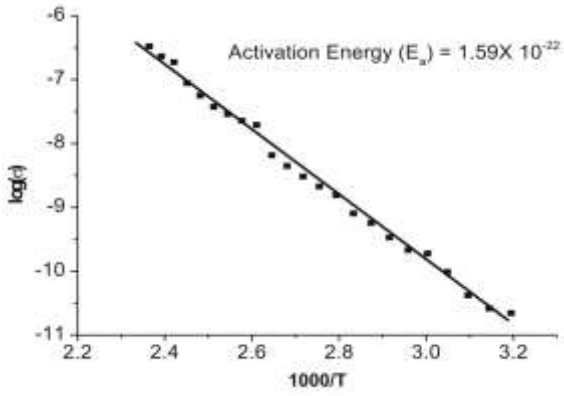


Fig.5: Electrical Conductivity Plot of SHMF Resin

The carrier motilities of the organic semiconductors might decrease due to:

A) The forces between the adjacent molecules are relatively weak as organic compounds from molecular crystals.

B) Due to little electronic coupling that exists between the adjacent molecules, it becomes difficult for the electrons to jump from one molecule to other.

C) As a consequence of the disordered structure which is due to amorphous nature, the electrons get scattered while traveling through the materials, when they try to flow through it and hence lowers the conductivity.

The study shows following results of electrical conductivity-

1) The electrical conductivity of SHMF resin lies in the range of 2.29 x10^{-11} to 2.36 x10^{-7} Siemen.

2) The plots of log σ versus 1/T is found to be linear in the temperature range under study, which indicate that the Wilson's exponential law $\sigma = \sigma o \exp(\Delta E/kT)$ is obeyed.

3) The energy of activation (Ea) of electrical conduction calculated from the slopes of the plots is found to be in the range of 1.59 x 10^{-22} J/K.

These observations and results are in harmony with the findings of other earlier workers [16-20, 34, 35]

Conclusion

Thermogram of the resin depicts four stages of decomposition. The observed weight loss is little higher than the calculated. This may be due to the degradation of side chain of resin. Activation energy by both Sharp-Wentworth and Freeman-Carroll method are in good agreement with each other. Low value of frequency factor [Z] it may be concluded that the reaction of decomposition of resin can be classified as a slow reaction. The negative values for entropy indicate that the activated polymer has more ordered structure than the reactants which are further supported by low Z value. The decomposition of resin is following first order kinetics although not perfectly. Electrical conductivity of this resin increases with increase in temperature which is the important property essential for the resin may be ranked as semiconductors. Hence, this new polymer may be semiconducting in nature.

Acknowledgement

The authors are thankful to the Head of the Department of Chemistry, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur for providing necessary laboratory facilities.

References:

1. Coppo P., Schroeder R., Grell M., Turner M.L.; Investigation of the electronic properties of cyclopentadithiophene polymers and copolymers Materials Research Society Symposium Proceedings 771(Organic and Polymeric Materials and Devices), CODEN: MRSPDH; ISSN: 0272-9172, 2003:61-64.
2. Kang S.W., Kim J.H., Oh K.S., Won J.; Effect of amino acids in polymer/silver salt complex membranes on facilitated olefin transport. J. of Membrane Sc., 2004;248: 201–206.
3. Nezel T., Fakler A., Zhylyak G., Mohr G.J., Keller S.; A highly sensitive NO_2-selective optode membrane, *Sensors and Actuators B*, 2000;70:165–169.
4. Coppo P., Grell M., Turner M.L.; Cyclopentadithiophene based electroactive materials.J. Mater. Chem., 2005;15: 1123–1133.
5. Colin F. P., Rena M. P.; Thermally stable, highly fluorinated stationary phases for gas chromatography, Analytica Chimica Acta ; 1987; 200:151-169.
6. Chandra R., Rajabi L., Soni R. K.; The effect of bismaleimide resin on curing kinetics of epoxy-amine thermosets , J.of Appl. Polym. Sc.; 1996; 62, 4:661-671.
7. Masram D.T.; Thermal Degradation Study of Terpolymer Resin derived from Salicylic acid, Diaminonaphthalein, Formaldehyde Terpolymer, E- J. of Chemistry; 2009; 6(3):830-834.
8. Das A.P.; S. Lenka; Nayak P.L.; Synthetic resins: I. Preparation and characterization of resins from substituted benzoic acid-formaldehyde, J. Appl. Polym. Sci. 1985; 30:4619.
9. Aristove L.J.; Kostantinov V.V.; Polymers with chelate bonding, derived from 8-quinolinol.; Izu. Tomsk. Politekhn. Inst.; 1961;111: 104-6.
10. Samal R.K.,Senapati B.K. ,Behuray T.B.; Synthesis and Characterization of Aniline-Doped Mixed Copolymer Resins-2.,J. Appl. Polym. Sci. ; 1996 ; 62 : 655.
11. DeGeiso R.C.; Donaruma L.G.; Tomic,E A., Polymeric Ligands, Separation of Uranium from Solutions and Ore Leaches with Salicylic Acid-Formaldehyde Polymers, Ind. Eng. Chem. Process Des. Dev., ACS pub.; 1963; 2 (1):43–44.
12. Michael P., Lingala P.; Juneja H., Paliwal L.; Synthetic, structural, and thermal degradation of a tercopolymer derived from salicylic acid, guanidine, and formaldehyde, J. Appl. polym.Sci.; 2004; 92:2278.
13. Masram D.T., Kariya K.P., Bhave N.S.; Kinetics of Thermal Degradation Study of Resin derived from Salicylaldehyde, Ethylenediamine and Formaldehyde; E-J.of Chemistry; 2010;7(2), 564- 568.
14. Ozawa T.; Applicability of Friedman Plot; J. Thermal Analysis; 1986; 3l: 547-551.
15. Manvalan R.; Patel M.M.; Synthesis and Study of Tercopolymers; J. Macromolecular Chem.; 1983; A-20 (9):907-925.

16. Talati A.M and Mistry V.N.;Semiconducting chelate polymers of dihydroxyquinones with cobalt Polymères semi-conducteurs de chélate par les dihydroxy-quinones avec le cobalt Halbleitende scherenpolymere von dihydroxy-chinonen mit kobalt. Materials Sc. and Eng. ; 1972; 10 : 287-290.
17. Han G., Shi G.; Porous polypyrrole/polymethylmethacrylate composite film prepared by vapor deposition polymerization of pyrrole and its application for ammonia detection. *Thin Solid Films*; 2007; 515, 17: 6986-699.
18. Kharadi G. J.; Panchani S. C.; Patel K.; D. Studies on Some Coordination Polymeric Chains of Metal Ions with QM1N. International Journal of Polymeric Materials; 2010; 59, 8 : 577 – 587.
19. Kanda S. , Kawaguchi S.; Electrical conductivity of some coordination polymers. J.Chem.Physics; 1961;34;1070.
20. Kanda S. , Kawaguchi S.; Synthesis of Co-ordination Compounds of High Molecular Weight. Bulletin of the Chemical Society of Japan; 1957; 30, 2: 192-193.
21. Masram D.T., Kariya K.P., Bhave N.S.; Synthesis of Resin-I: Salicylic acid hexamethylenediamine and Formaldehyde and its ion exchange properties, epolymers; 2007; ISSN 1618-7229,75,.
22. Masram D.T., Kariya K.P., Bhave N.S.; Synthesis, characterization and thermal degradation study of terpolymer derived from p-hydroxybenzoic acid, diaminonaphthelein with formaldehyde,High Perform. Polym.; 2010; 22, 8:1004 -1016.
23. Jadhao M.M., Paliwal L.J., Bhave N. S.; Resin I: Synthesis and characterization of 2, 2′-dihydroxybiphenyl-urea-formaldehyde terpolymers, J. Appl. Polym. Sci.; 2005, 96, 5; 1605 - 1610.
24. Masram D.T., Kariya K.P., Bhave N.S.; Thermal Degradation Study of Terpolymer Resin derived from Salicylicacid –Ethylenediamine- Formaldehyde, *Thermans DAE-BRNS 6th National Symposium & workshop on Thermal Analysis, India*; 2008: 329-331.
25. Freeman E.S., Carroll B.J.; The Application of Thermoanalytical Techniques to Reaction Kinetics: The Thermogravimetric Evaluation of the Kinetics of the Decomposition of Calcium Oxalate Monohydrate, Phys. Chem. 1958; 62, 4, : 394–397.
26. Freeman E.S., Anderson D.A.; The kinetics of the thermal degradation of polystyrene and polyethylene, J. Polym. ; 1961; 54, 159: 253 – 260.
27. Sharp J.B.; Wentworth S.A.; Kinetic analysis of thermogravimetric, Anal. Chem. 1969; *41* (14): 2060–2062.
28. Coats A.W.; Redfen J.P.; Kinetic parameters from thermogravimetric data. II. J. of Polym. Sc. Part B: Polymer Letters 2003;3, 11:917 – 920.
29. Ozawa T.; Kinetics of non-isothermal crystallization; J. Thermal Analysis;1971;12, 3: 150-158.
30. Jacobs P.W.M.; Tompkins F.C.; *Chemistry of Solids State, E.G., Garner Publication, London;* 1955;188.
31. Azaroff L.V.; *Introduction to Solids, McGraw Hill Inc. New york* ; 1960.
32. Dunlop W.V.; *An introduction to semiconductors, Wiley, New York,*;1957;189.
33. Fanun M.; Conductivity, viscosity, NMR and diclofenac solubilization capacity studies of mixed nonionic surfactants microemulsions. J.Molecular Liquids;2007;135, 1-3:5-13.
34. Masram D.T., Kariya K.P., Bhave N.S.; "Electrical conductivity study of resin synthesized from salicylic acid, butylenediamine and formaldehyde," Archives of Applied Science Research; 2010;2(2):153-161.
35. Masram D.T., Kariya K.P., Bhave N.S.; "Physicochemical Studies Of Resins Derived From p- Hydroxybenzoic Acid, Diaminobenzoic Acid With Formaldehyde And Its Electrical Conductivity Study" Journal of Chemistry (JC); 2011;01:1-8.

Table1: Thermoanalytical data and decomposition temperature of SHMF resin

Terpolymer	Temperature Range (°C)	Stage of Decomposition	Species Degraded	% Weight loss	
				Observed	Calculated
SHMF	40-160	First	Loss of entrapped - H_2O molecule	6.3	6.1
	160-240	Second	Loss of side chain attached to aromatic nucleus and -COOH group.	64.2	64.5
	240-420	Third	Loss of phenolic -OH group.	70.0	70.2
	420-800	Fourth	Complete decomposition	100	100

Table2: Result of thermogravimetric analysis of SHMF resin

Decom-position Temp. (T)	Half Decom-position Temp. (T*)	Activation Energy kJ/mole		Kinetic parameters by FC				
		Freeman-Carroll FC	Sharp-Wentworth SW	Entropy change ΔS(J)	Free energy change ΔF(kJ)	frequency factor Z (S^{-1})	Apparent entropy S*(J)	n
220	225	18.96	17.86	7.9	17.18	2089.296	-22.0411	0.99

Table 3: Evaluation of Activation Energy of Conduction SHMF Resin

Diameter of the pellet = 1.289

Surface area of the pellet (A) = πr^2 = 3.142 x $(0.645)^2$ = 1.305 cm^2

Thickness of pellet (l) = 0.191 cm.

A/l = 6.832 cm.

Temp (K)	1000/T (K^{-1})	Resistance in Ohm 'R'	Resistivity p = RA/l (Ohm.cm)	Electrical Conductivity $\sigma = 1/\rho$ (Siemen.cm^{-1})	Logσ
313	3.1949	6.38×10^{9}	4.36×10^{10}	2.29×10^{-11}	-10.6394
318	3.1447	4.56×10^{9}	3.12×10^{10}	3.21×10^{-11}	-10.4935
323	3.0960	2.81×10^{9}	1.92×10^{10}	5.21×10^{-11}	-10.2833
328	3.0488	1.24×10^{9}	8.47×10^{9}	1.18×10^{-10}	-9.9280
333	3.0030	8.67×10^{8}	5.92×10^{9}	1.69×10^{-10}	-9.7726
338	2.9586	6.86×10^{8}	4.69×10^{9}	2.13×10^{-10}	-9.6709
343	2.9155	4.41×10^{8}	3.01×10^{9}	3.32×10^{-10}	-9.4790
348	2.8736	1.73×10^{8}	1.18×10^{9}	8.46×10^{-10}	-9.0726
353	2.8329	1.81×10^{8}	1.24×10^{9}	8.09×10^{-10}	-9.0923
358	2.7933	8.71×10^{7}	5.95×10^{8}	1.68×10^{-9}	-8.7746
363	2.7548	6.03×10^{7}	4.12×10^{8}	2.43×10^{-9}	-8.6149
368	2.7174	4.94×10^{7}	3.38×10^{8}	2.96×10^{-9}	-8.5283
373	2.6810	3.61×10^{7}	2.47×10^{8}	4.05×10^{-9}	-8.3921
378	2.6455	2.53×10^{7}	1.73×10^{8}	5.78×10^{-9}	-8.2377
383	2.6110	1.49×10^{7}	1.02×10^{8}	9.82×10^{-9}	-8.0078
388	2.5773	9.01×10^{6}	6.16×10^{7}	1.62×10^{-8}	-7.7893
393	2.5445	7.46×10^{6}	5.10×10^{7}	1.96×10^{-8}	-7.7073
398	2.5126	5.66×10^{6}	3.87×10^{7}	2.59×10^{-8}	-7.5874
403	2.4814	3.30×10^{6}	2.25×10^{7}	4.44×10^{-8}	-7.3531
408	2.4510	2.14×10^{6}	1.46×10^{7}	6.84×10^{-8}	-7.1650
413	2.4213	1.21×10^{6}	8.27×10^{6}	1.21×10^{-7}	-6.9174
418	2.3923	8.14×10^{5}	5.56×10^{6}	1.80×10^{-7}	-6.7452
423	2.3641	6.21×10^{5}	4.24×10^{6}	2.36×10^{-7}	-6.6277