

Preparation, Characterization, and Thermal Properties of New poly (ester-imide)s derived from Poly condensation Reaction between Diimide-dicarboxylic Acid with Aromatic Diols

Prof. Dr. Mohammed Ali Mutar^{1*}, Farah Safi Khlewee² and Ruaa Jameel Kamel³

1. Faculty of Engineering, University of Al-Qadisiyah, Iraq. 2. Faculty of Education, University of Al-Qadisiyah, Iraq.
3. Faculty of Pharmacy, University of Al-Qadisiyah, Iraq.

²farah.s.khiwi@eq.edu.iq, ³ruaa.kamel@eq.edu.iq

Correspondence author: Prof. Dr. Mohammed Ali Mutar, e-mail: mohammed.ali@qu.edu.iq

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Abstract

Polymeric systems based on poly (ester-imide)s (PEIs) are high-performance material, which combines the useful properties of polyester and polyimide resins. A chain of new poly(ester-imide) are obtained through polycondensation between diimide-dicarboxylic acid (Prepared from reaction pyromellitic anhydride (PMDA) with diamine) with aromatic diols such as Bis(2-bromo 4-hydroxy phenyl) cyclohexane (M1) and Bis(4-hydroxy phenyl)-2-hydroxy phenylmethane (M2) in the presence of dibutyltin dilaurate as Catalyst, The corresponding new poly(ester-imide) (PEIs) that are gained in quantitative products are soluble in polar aprotic solvents, are of high thermal stability. The structures of the Monomers and poly(esters-imide) were confirmed by FTIR and ¹H NMR spectroscopies.

Keywords: Poly (esters-imide), Diamine, Pyromellitic Anhydride (PMDA), Polycondensation, Dicarboxylic Acid.

Introduction

Because of the growing needs for polymers of high-performance as a substitution for metals and ceramics in the aerospace, microelectronic and automotive products, polymers that are heating stable are gained a lot of attention during ten years. Polyimides and their copolymers are the most beneficial types of high performance, which are used in many applications in the industry [1-2]. Polyimides have attracted a lot of interest because of their extraordinary thermal stability, good mechanical and electrical characteristics [3]. Nevertheless, the hard task lies in its processing, resulted from poor flow features and infusibility, has limited their applications. The preparation of poly (ester-imide)s was evolved to solve such complications [4]. Employment of flexible ester association can decrease the heat of processing and enhance the flow property instead of the thermal stability.

Moreover, a lot of poly (ester-imide)s have been stated to show liquid crystalline phases [5-8]. Amongst them, poly (ester-imide) (PEIs) draw scientific attention because they include good mechanical characteristics of polyimides and the biodegradability of polyesters [9]. PEAs have various applications as single-use bags, agricultural films, drug carriers, and matrix resins for biomedical materials [10-13]. Poly (ester imide)s are researched only in the narrow viewpoints of film basic properties

like thermal stability and solubility, and mechanical characteristics, [14]. Many of the formerly stated poly(ester imide)s were synthesized through direct polymerization of polyester from imide-containing di carboxylic acid with diols without the pathway of thermal imidization that plays an important role for spontaneous inplane Orientation [15]. This work includes preparation of new poly(ester-imide) (PEIs) from reaction diols such as (M1, M2) with diimide-dicarboxylic acid such as compounds (M5, M6) in the presence of dibutyltin dilaurate and qualitative analysis of the monomers and polymers are achieved through FT-IR, and ¹H NMR spectroscopies, thermal stability have been thoroughly examined by (TGA).

Experimental

Materials

Dichloromethane, Chloroform, Cyclohexane, Sodium hydroxide, acetic acid, pyridine, methanol, and Nitric acid all from (BIOSOLVE); Hydrochloric acid, Salicylaldehyde, 3-bromophenol, phenol, Furfural, Hexane, pyromellitic anhydride, 4-bromobenzaldehyde, Aniline, 2-chloroaniline, 3-bromoaniline, Pyridine, acetic acid, dibutyltin dilaurate, Dimethyl Sulphoxide (DMSO), Tetrahydrofuran (THF), and thioglycolic acid all from (MERCK company); N, N-Dimethylformamide (ALDRICH company), Ethanol (Scharlab S.L company).

The instruments: Its showed in the table (1):

Table 1: The Instruments used in the Study

Instrument	Company	The state
FTIR 8400S, Fourier Transform infrared spectrophotometer	SHIMADZU	Japan
Oven	Trip International Corp	Italy
Hot plate stir	BibbyStrlntd	UK
Thermogravimetric analysis (TGA)	Polymer laboratories Co	England
Stuart smp30	Measuring the degree of fusion	
Shiel 300MHZ	recorded NMR spectra	Switzerland
Land by using (DMSO-d6)	University's Educational teacher	Tehran Iran
Model PL-TG	Iran polymer & petrochemical institute	Iran

Preparation of monomer

Bis(2-bromo 4-hydroxy phenyl) cyclo hexane) (M1)

A mixture of each following:

- 1- 3-bromo phenol 4gramm (42mmol).
- 2- cyclohexanone 2.72gram (16mmol).
- 3- thioglycolic acid (0.5gram)
- 4- HCl catalyst (37.5gram)

All the previous compounds kept at the flask and made mechanical stirrer and heating at (60) °C for six hours. Then the mixture should be cold to stop the reaction. Follow washing and drying [16]. Yellow crystals are (85) % of the products, M.P is (187-190) °C.

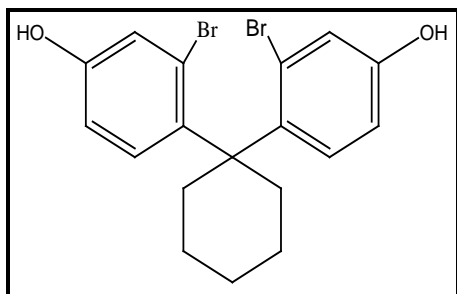


Figure-1: Structure of M1

Bis (4-hydroxy phenyl) -2-hydroxy phenyl)methane (M2)

To a 0.1M solution of H₂SO₄ in salicylaldehyde (1.5gram) (12mmol), phenol (21mmol) (2gram), methanol (60- 40) %, and salicylaldehyde (1.5gram) (12mmol) are mixed for ten hours at (120) °C with the continuous stirring. After completing the reaction, the solution is distance beneath vacuum (17). Brown crystals (71) % is Products, M.P=(80°C) crystals.

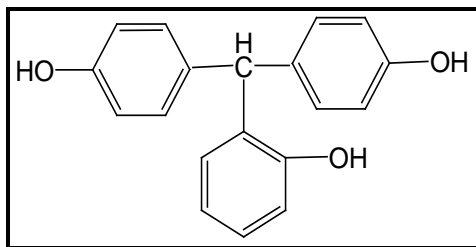


Figure-2: Structure of M2

Bis (4-amino 2-chloro phenyl)4-bromo phenyl methane (M3)

To a 0.1M solution of H₂SO₄ in methanol (60-40) %, 2-chloro Aniline (21mmol) (2gram) and 4-Bromo benzaldehyde (1.5 gram) (12mmol) are joined, and the combination was refluxed for ten hours at 120°C with the continuous mixing. After completing the reaction, the solution was distanced beneath vacuum [17]. The product took the form of (71%) brown crystals, M.P=(230°C) crystals.

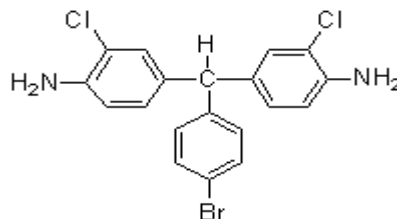


Figure-3: M3 (BACPBPM) structure

The monomer 4, 4'-(furan-2-ylmethylene)dianiline (M4) synthesized by the similar method that (M3) is made, but by employing ingredients such as Aniline, and Furfural with the mixture of methanol and H₂SO₄ as a catalyst.

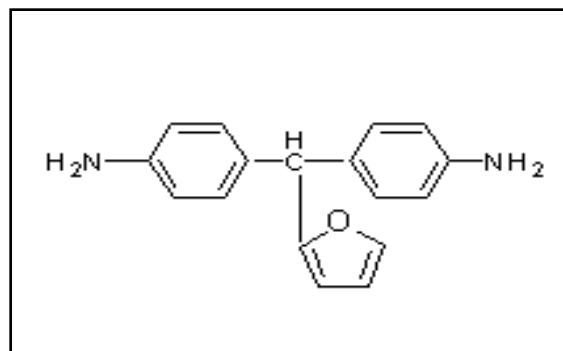


Figure-4: Structure of M4 (BAPFM)

Table-2: Properties of aromatic diamines

N O	Mono mer	Substance	Col our	Yiel d%	M. P/°c
1	BACP BPM	and 4-Bromo benzaldehyde (1.5gm, 12mmol)	2-chloro Aniline (2gm, 21mmol)	Brown	71 % 230 °C
3	FMD A	Furfural 1.5gm (15 mmol)	Aniline 3gm (32 mmol)	Black	90 % 200 °C

Preparation of dicarboxylic acid compounds

Preparation of 2, 2'-(((4-bromophenyl) methylene) bis (3-chloro-4,1-phenylene)) bis (1,3-dioxoisindoline-5-carboxylic acid (M5)

In a 250 mL round-bottomed flask are joined (20 mmol) (3.84 gram) of pyromellitic anhydride,

2gm(4mmol) of(BACPBM),acetic acid (80) ml and pyridine (3:2), and a moving bar. The combination was mixed at room temperature overnight and then refluxed for 4 hours. The solution was distanced beneath condensed pressure,and the remainder was melted in 100 mL of cold water. Then 5 MI of concentrated HCl was joined. The solventwas moved till a yellow precipitate was shaped, and the precipitate was filtered off and dried [18] to yield4.95 g (90.3%) of the yellow crystal composite.

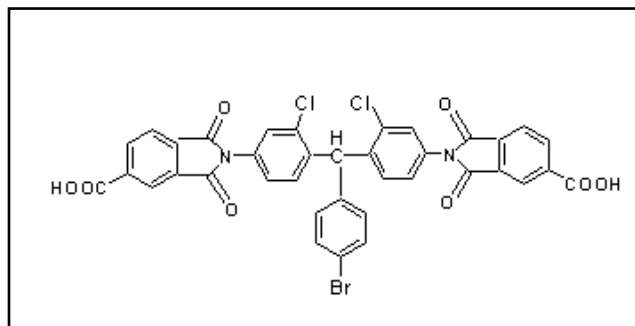


Figure-5: Structure of (M5)

The dicarboxylic acid 2, 2'-((furan-2-ylmethylene) bis (4,1-phenylene)) bis(1,3-dioxoisindoline-5-carboxylic acid) (M6) synthesized in the same method above using materials BAPFM, pyromellitic anhydride acetic acid and pyridine.

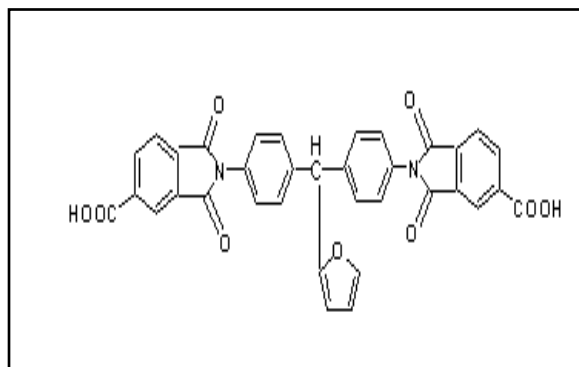


Figure-6: Structure of (M6)

Table-3: Diacids properties

NO	Dicarboxylic acids	Color	Yield%	M.P/ ^o C
1	M5	Brown	61%	396 ^o C
2	M6	yellow	70%	375 ^o C

Prerparation of poly (ester-imide)s

As shown in (Table3),Dihydroxy monomer and Di Carboxylic acidareblended at 120^oC beneath continuous stirring.

When the acid contents are dissolution imide in Dihydroxy monomers, the dibutyltinedilurate (0.15 wt (%)) are joined, and the temperature was raised to 160^oC for 1hour. The constituents are dried beneath the vacuum[19].

Table-4: Properties of poly (ester-imide) [PEI₁-PEI₂]

polyester	Monomers		Diacid gm/mmol	Dihydroxy gm / mmol	Yield (%wt.)	Color
	Diacid	Dihydroxy				
P.E1	M5	M1	1.2gm	1gm	88%	white
P.E2	M6	M2	2.4gm	1.3gm	85%	Orang

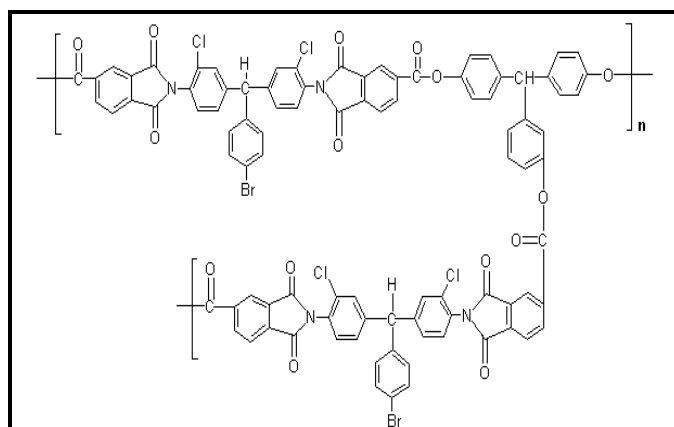


Figure-7: structure of PEI2

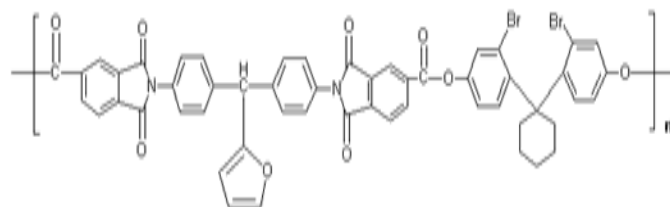


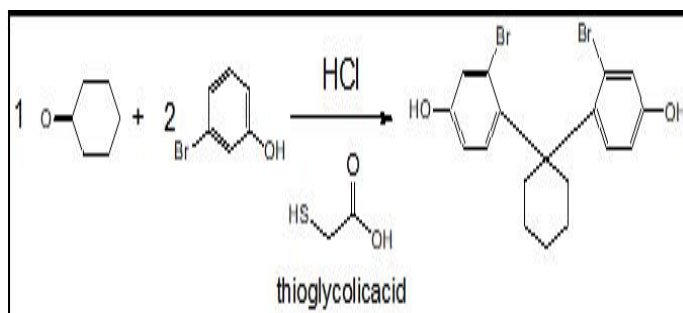
Figure-8: Structure of PEI2

Results and Discussion

Prerparation of monomers

Prerparation and characterization (M1)

Cyclohexanon (One molecule) with 3-bromo phenol (two molecules) will produce monomer in the existence of thioglycolic acid and acid as a catalyst for six hours at 60^oC. It's defined by FTIR.



Scheme-1: Prerparation of (M1)

The FTIR spectra of (M1) as displayed in a table (5):

Table-5: FTIR spectra of (M1) and absorption band

Spectra of (M1)	absorption band
c-c aromatic	1589cm ⁻¹
C-H Aromatic	3031 cm ⁻¹
OH	3286 cm ⁻¹
C-H aliphatic	2970 cm ⁻¹
C-O	1164 cm ⁻¹
C-Br	656cm ⁻¹

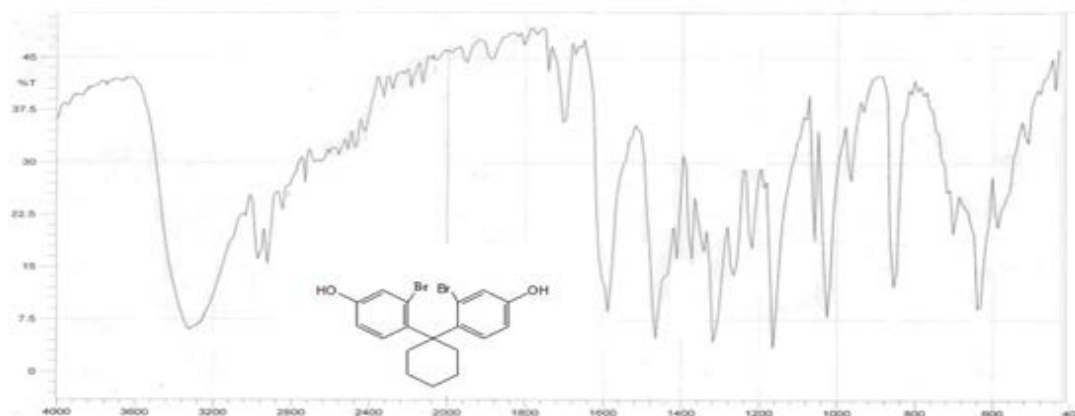


Figure-9: FTIR spectra of (M1)

Prerparation and Characterization of (M2)

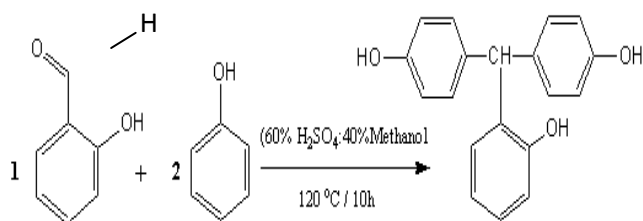
This monomer is made through the concentration of salicylaldehyde (one molecule) with phenol (two molecules) in the company of H₂SO₄ and methanol as catalysts at 120 °C for 10 hours. It's defined by FTIR.

Scheme-2: M2Prerparation

M2 Characterization and Prerparation

M2 FTIR spectra as a revealed table (6)[20].

Table-6: M2FTIR spectra and absorption band



The FTIR spectra	absorption band
C=C Aromatic	(1666) cm ⁻¹
C-H Aromatic	(3062) cm ⁻¹
OH	(3379) cm ⁻¹
C-H aliphatic	(2862) cm ⁻¹
C-O	(1095) cm ⁻¹

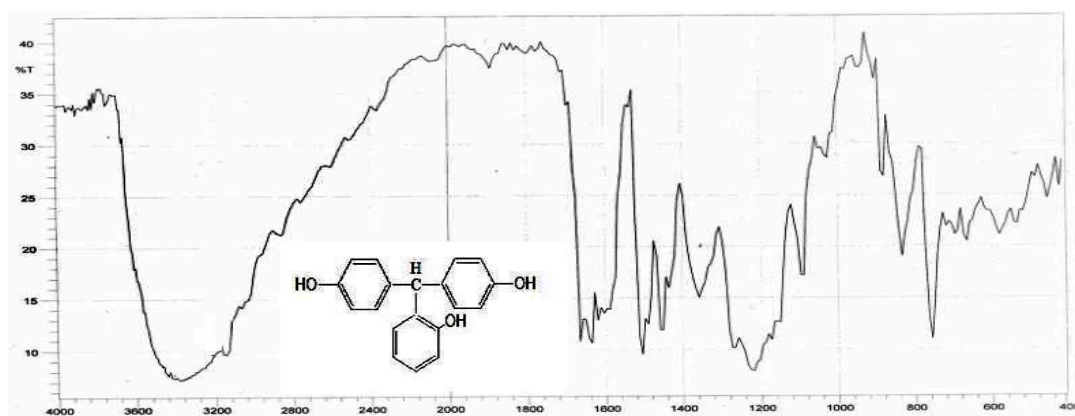
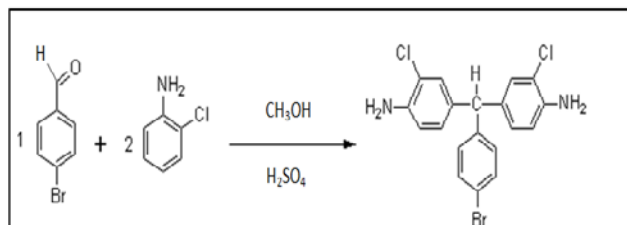


Figure-10: FTIR spectra of (M2)

Prerparation and Characterization of (M3)

This monomer was made by the concentration 4-bromo benzaldehyde (one molecule) and 2-Chloro aniline (two molecules) in the company of H₂SO₄ and

methanol as catalysts at 120 °C for 10 hours. It's defined by FTIR.



Scheme-3: Prerparation of (M3)

Characterization of [M3]

FTIR spectrum

Table-7: FTIR spectra of (M3) and absorption band

FTIR spectrum	absorption band
(C=C Aromatic),	(1579) cm^{-1}
(C-H Aromatic),	(3116) cm^{-1}
(NH ₂),	(3300) cm^{-1}
(C-H aliphatic),	(2862) cm^{-1}
(C-N)	(1226) cm^{-1}
C-Cl,	(779) cm^{-1}
C-Br	(672) cm^{-1}

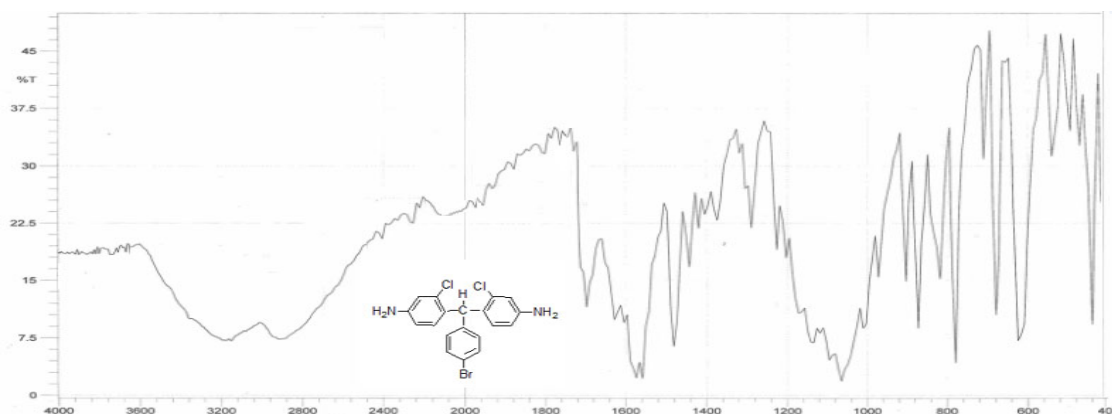
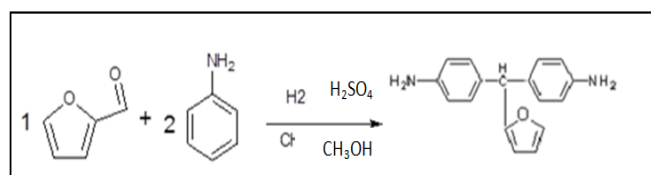


Figure-12: FTIR spectra of (M4)

Prerparation and Characterization of (M4)

The monomer produced from Furfural (one molecule) and the aniline (two molecules) in the attendance of H₂SO₄ and methanol as catalysts at 120 °C for 10 hours. It's defined by FTIR.



Scheme-4: (M4) Prerparation

Table-8: FTIR spectra of (M4) and absorption band

The FTIR spectra	absorption band
C=C Aromatic	(1597) cm^{-1}
C-H Aromatic	(3055) cm^{-1}
NH ₂	(3355) cm^{-1}
C-H aliphatic	(2916) cm^{-1}
C-N	(1280) cm^{-1}
C-O	(1175) cm^{-1}

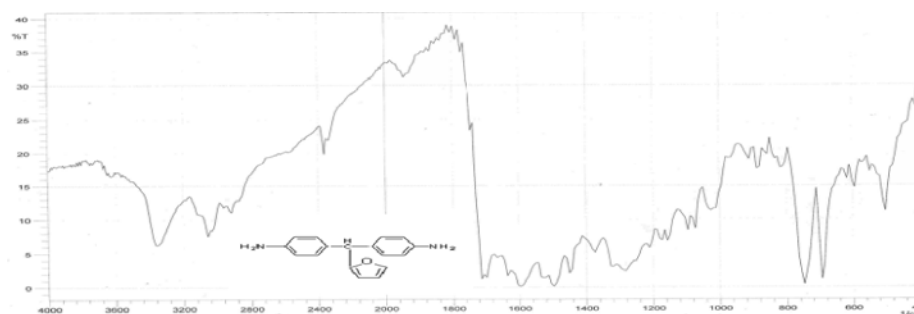
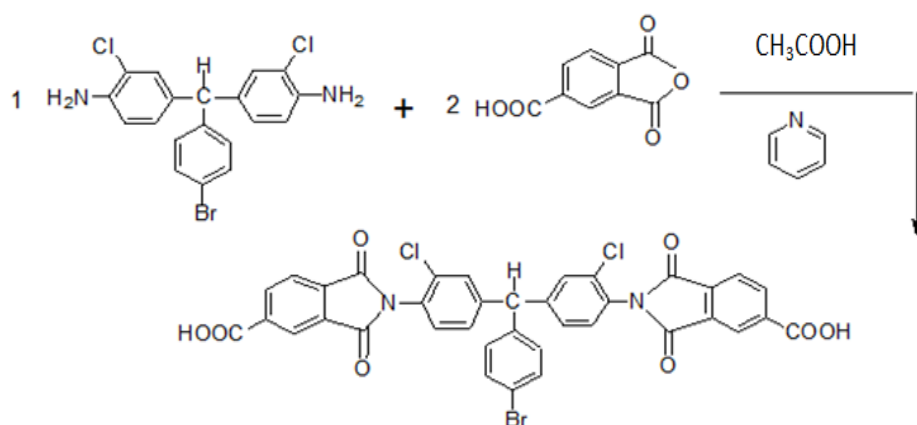


Figure-13: (M4) FTIR spectra

Dicarboxylic acid Prerparation and Characterization (M5) Prerparation and Characterization

The monomer acid was made by (BACBPBM) (1 molecule) and pyromellitic dianhydride

(2molecules)with the present of pyridine and acetic acid at 25 C for 24 hours then refluxed for 4 hours. This composite was defined by FTIR.



Scheme-5: Prerparation of M5

Table-9: FTIR spectra of (M5) and absorption band

The FTIR spectra	absorption band
C=C Aromatic	(1597) cm^{-1}
C-H Aromatic	(3062) cm^{-1}
OH	(3394) cm^{-1}
C-H aliphatic	2977 cm^{-1}
C-N	(1288) cm^{-1}
C-O	(1194) cm^{-1}
(C=O)	1694 cm^{-1}
C-Br	610 cm^{-1}
C-Cl	740 cm^{-1}

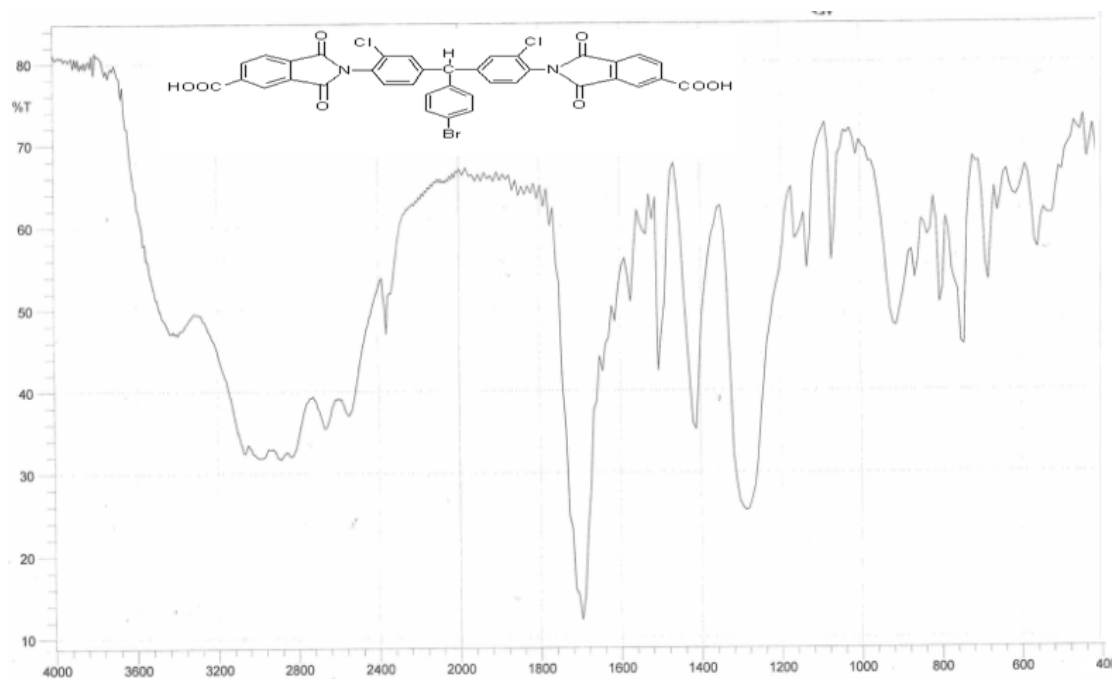


Figure-14: (M5) FTIR spectra

(M5)M2is displayed in Figure (15) gives the subsequent changes;

1. (DMSO) = δ (2.432) ppm
2. (CH) = δ (5.190) ppm

3. (Ar-H) = δ (7.713 -8.906)ppm
4. (COOH) = δ (13.205)ppm

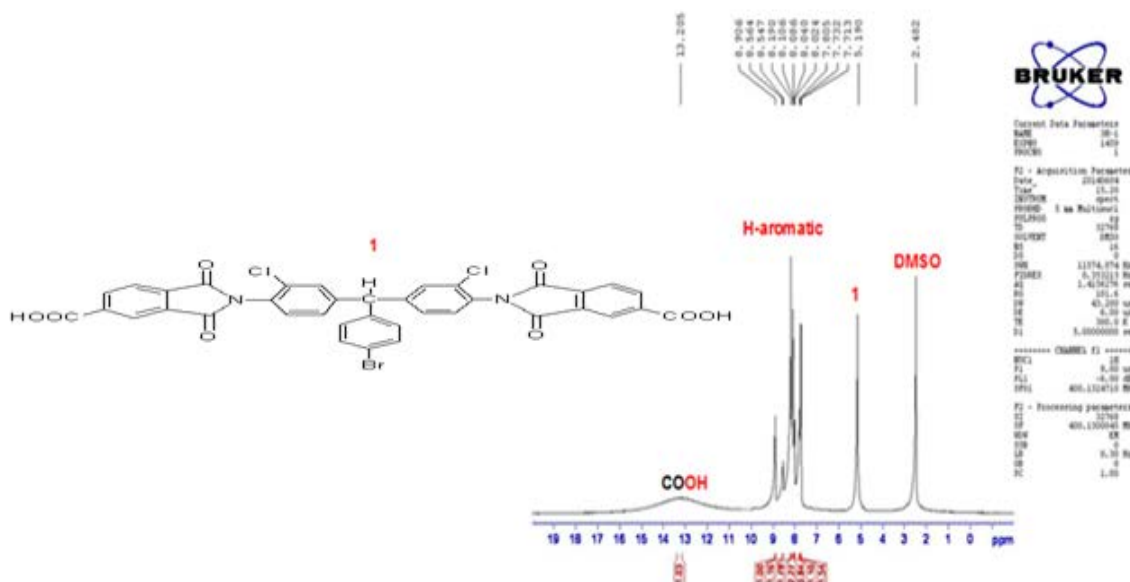


Figure 15¹: HNMR spectra of (M5)

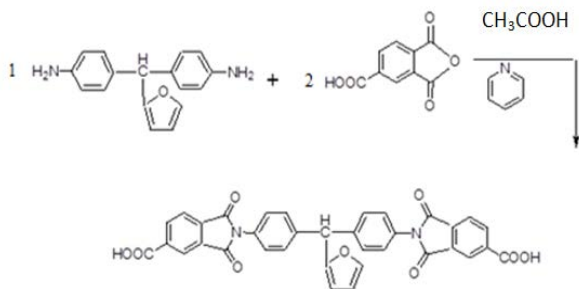
(M6) Preparation and Characterization

The monomer was created by the concentration of (BAPFM) (1 molecule) with pyrotrimellitic dianhydride (2 molecules) in the company of pyridine and acetic acid and after that, it refluxed for 4 hours at room temperature overnight. This composite was defined by FTIR.

The FTIR spectra of (M6) as a table (10).

Table-10: FTIR spectra of (M6) and absorption band

FTIR spectra	absorption band
C=C Aromatic,	(1604) cm ⁻¹
C-H Aromatic	(3100) cm ⁻¹
OH	(3250) cm ⁻¹
C-H aliphatic	(2800) cm ⁻¹
C-N,	(1296) cm ⁻¹
C-O	(1172) cm ⁻¹
C=O	(1692) cm ⁻¹



Scheme-6: Preparation of M6



Figure-16 : FTIR spectra of (M6)

¹H-NMR spectrum of (M6), is revealed in Figure(17) gives the subsequent changes;

- 1- DMSO = δ (2.147) ppm
- 2- CH δ = (7.547, 7.639) ppm

- 3- Ar-H = δ (7.547 -7.639)ppm
- 4- COOH = δ (13.172) ppm

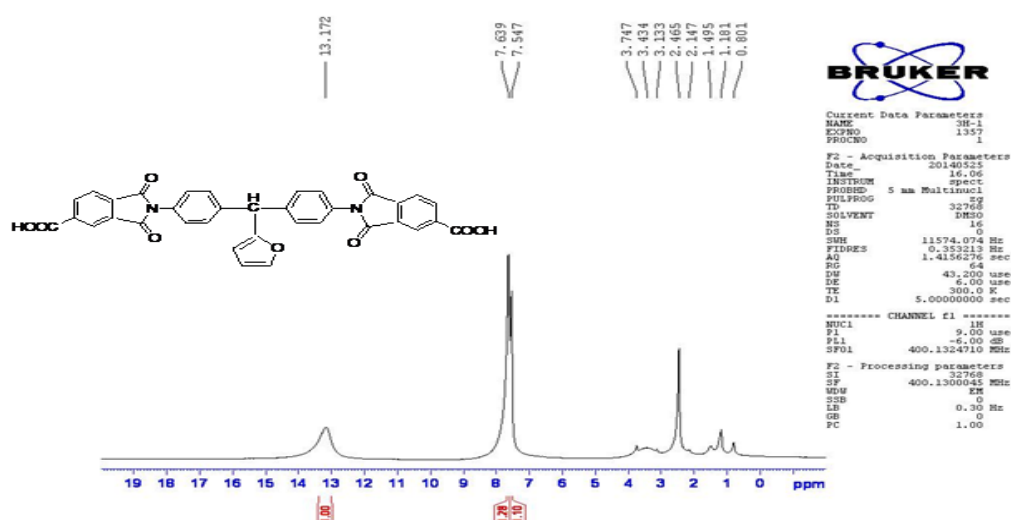
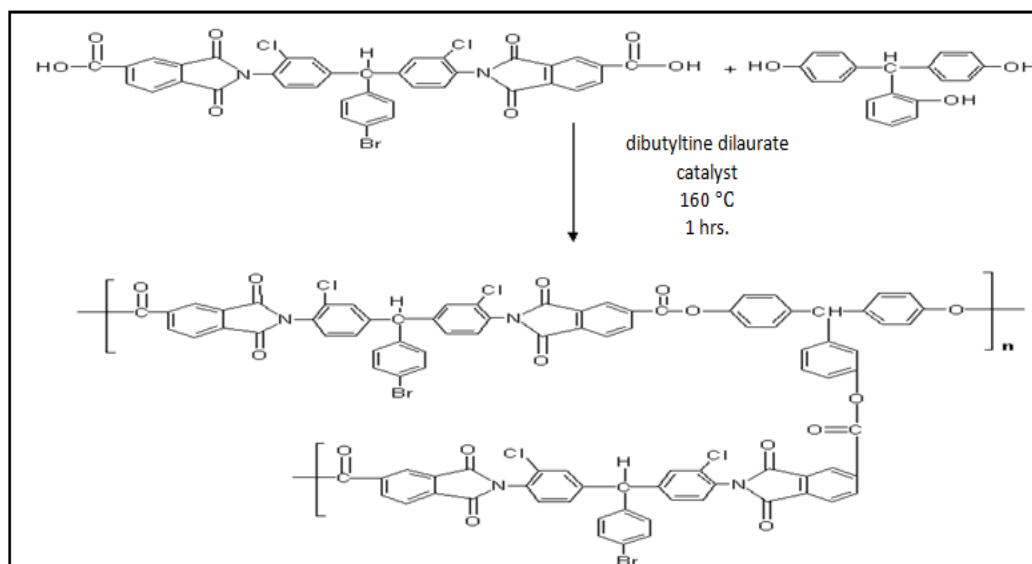


Figure-17¹: HNMR spectra of (M6)

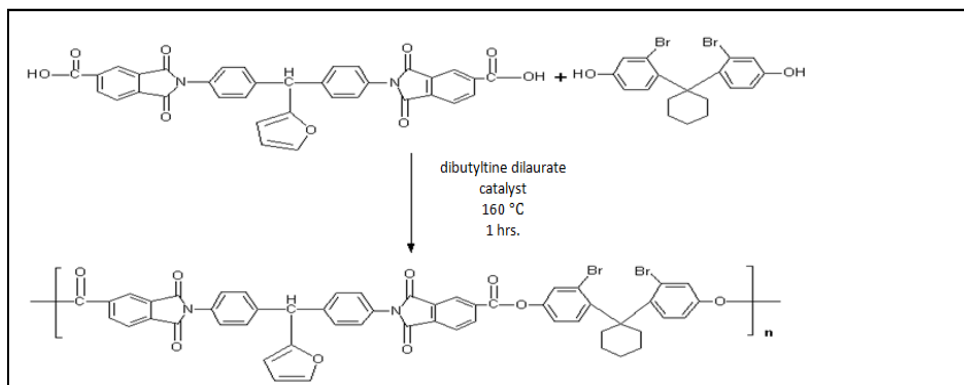
Prerparation of polyester [PEI 1-PEI 2]

Polycondensation procedure used for prerparation of sequences(M5,M6)dicarboxylic acidof new diverse aromatic dihydroxyl monomer [M1,M2], by employing the dibutyltin dilaurate catalyst(0.15

wt.(%). It has a delicatepartlike methylene unit and a ring of the pyridine heterocyclicin key series for increase reaction with organic compounds. (ester-imide)s were defined by FT-IRand¹H-NMRspectra.



Scheme-7: Prerparation of (PEI1)



Scheme-8: Prerparation of (PEI)

Characterization of poly (ester-imide)s [PEI1-PEI2] The FTIR spectra of (PEI1) as in table (11).

Characterization of PEI 1

FTIR spectrum of PEI 1

Table-11: FTIR spectra of (PEI1) and absorption band

The FTIR spectra of	absorption band
C=C Aromatic	1589cm ⁻¹
C-H Aromatic	3093 cm ⁻¹
C-H aliphatic	2962 cm ⁻¹
C-N	1272 cm ⁻¹
C-O	1103cm ⁻¹
C=O ester	1741 cm ⁻¹
C-Cl	733 cm ⁻¹
C-Br	672 cm ⁻¹

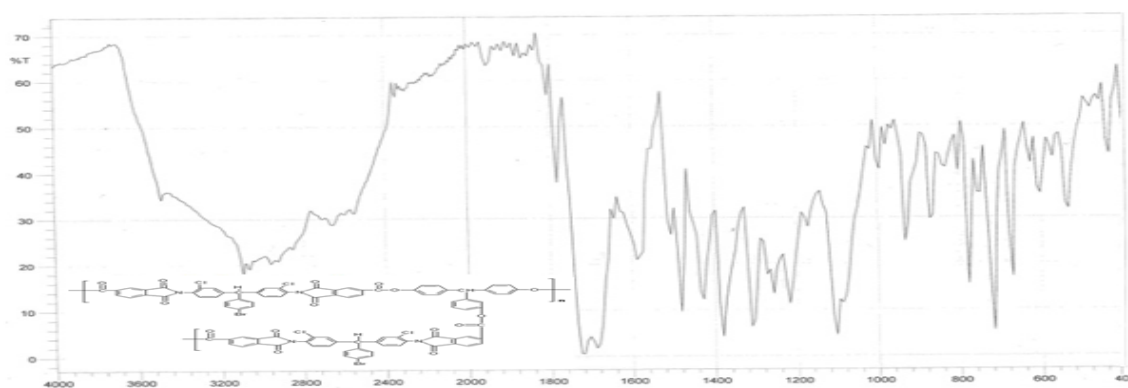


Figure-18: FTIR spectra of (PEI1)

(PEI1) Spectrumis revealed in Figure (19) as:

- 1- DMSO = δ (2.358 -2.986) ppm
- 2- CH = δ (1.200-1.889) ppm

- 3- Ar-H = δ (6.588-8.588)ppm
- 4- OH = δ (3.986-3.728) ppm.

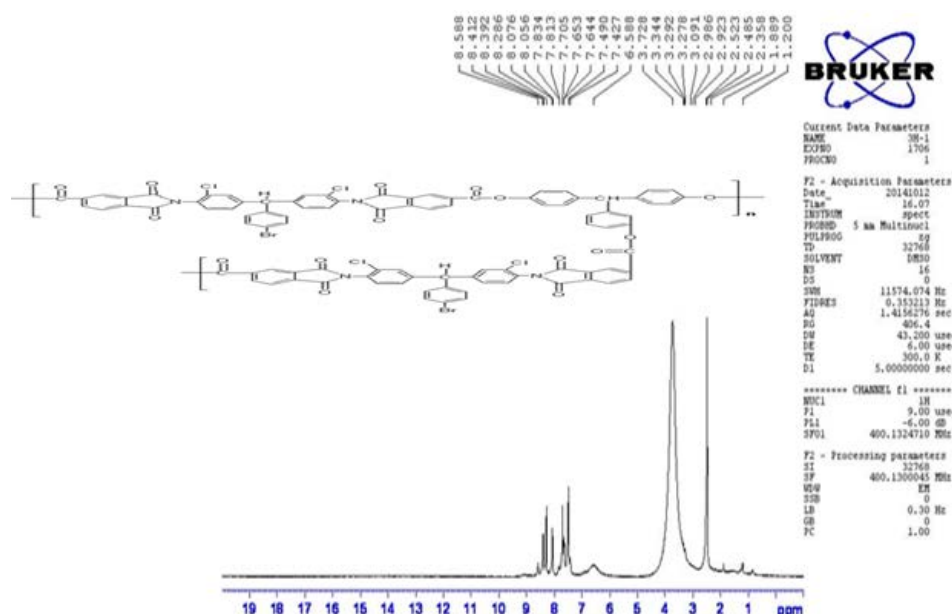


Figure-19¹: HNMR spectra of PEI1

FTIR spectrum of PEI 2

The FTIR spectra of (PEI2) as presented in table (11).

Table-12: FTIR spectra of (PEI2) and absorption band

The FTIR spectra	absorption band
C=C Aromatic	1596cm ⁻¹
C-H Aromatic	3055 cm ⁻¹
C-H aliphatic	2954 cm ⁻¹
C-N	1288 cm ⁻¹
C-O	1164cm ⁻¹
C=O ester	1704 cm ⁻¹
C-Br	684cm ⁻¹

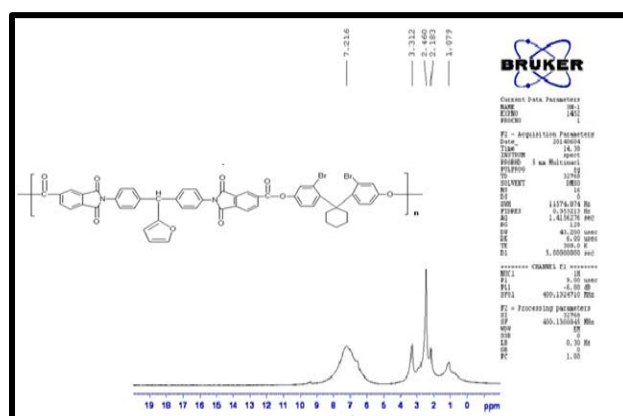


Figure 21¹: HNMR spectra of PEI2

The solubility of poly (ester-imide)s

The solubility of polyesters PEI1-PEI2 is qualitatively examined in organic solutions; the outcomes were shown in (Table 4). The way which tries to improve the process capabilities and solubility were presenting pliant linkages, bulky groups, or molecular corresponding. The supplement of bulky pendant groups in polymer backbone not only could afford an improved solubility due to reduce packing density and crystallinity [21]. Main purposes of our study were making better solubility polyesters. The Solubility is tested as (0.01) gram of polymeric sample insolvent (2) ml. Most new artificial polyesters have high soluble in common dipolar and polar a protic solvents and does not require heating.



Figure-20: FTIR spectra of (PEI2)

(PEI2)OH is displayed in Figure(21) as

- 1- DMSO = δ (2.183-2.460) ppm
- 2- CH = δ (1.979) ppm
- 3- Ar-H = δ (7.216) ppm
- 4- OH = δ (3.312) ppm

Table-13: Solubility of poly (ester-imide)s

Solvent	Poly(ester-imide)	
	PEI ₁	PEI ₂
pyridine	+-	++
CHCl ₃	+-	++
CH ₂ Cl ₂	++	++
NaOH	+-	+-
H ₂ SO ₄	+-	+++
HNO ₃	++	+-
Acetone	+-	+-
Benzene	++	++
DMF	++	+-
DMSO	+++	++
THF	++	+-

- 1- +++ complete soluble
- 2- ++Soluble at 25 C room temperature
- 3- +- partially or semi-complete Soluble

Poly (ester-imide)s thermal analysis

Thermogravimetric Analysis includes defining variations in mass temperature function. It is usually employed to study temperatures, absorbed of materials, concentrations of inorganic and organic parts [22]. It uses a delicate electronic balance by a temperature programmer. The thermal characteristics of four examples of this polyester were examined through thermogravimetric analysis (TGA) in Argon atmosphere at a heating rate of 10°C/min and the outcomes as $T_i, T_{op}, T_f, T_{50\%}$, percentage of the residue at temp (800)°C, and produces of the char at temp (500) °C are shown in (Table 4).50% weight loss temperatures of (PEI₁-PEI₂)as a standard reference are all temp (700-800) °C, char produces of (PEI₁-PEI₂) at temp (500) °C is 58% until 66% in Argon atmosphere that refers to they could encounter high-temperature resistant needs as particular distinctive supplies. Weight residue of (PEI₁) at temp (800) °C is higher (56%) than (PEI₂) (51%).

Table-14: Poly (ester-imide)s thermal behavior data.

Aromatic poly(ester-imide)s	DT/°C				T ₅₀ %	Residue at °C800	Char % at 500°
	T _i	T _{op} ₁	T _o _{p2}	T _f			
PEI1	23	40	-----	80	80	56%	66%
PEI2	22	30	-----	80	79	51%	58%

imide)s							C
PEI1	23	40	-----	80	80	56%	66%
	4	0		0	0		
				<			
PEI2	22	30	-----	80	79	51%	58%
	0	0		0	9		
				<			

DT:temperature of Decomposition.

T_i : Initial temperature of decomposition.

T_{op} :temperature of Optimum decomposition.

T_f : temperature of Final decomposition.

T_{50%}:50% weight loss Temperature, got from TGA.

Char% at 500°C: Residual weight percentage at 500°C in Argon by TGA

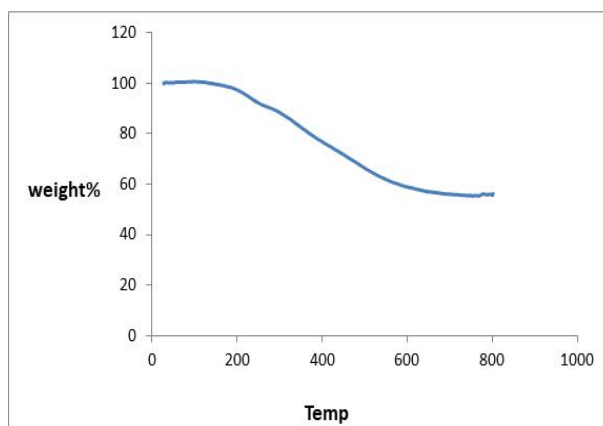


Figure-22: TGA curve of PEI1

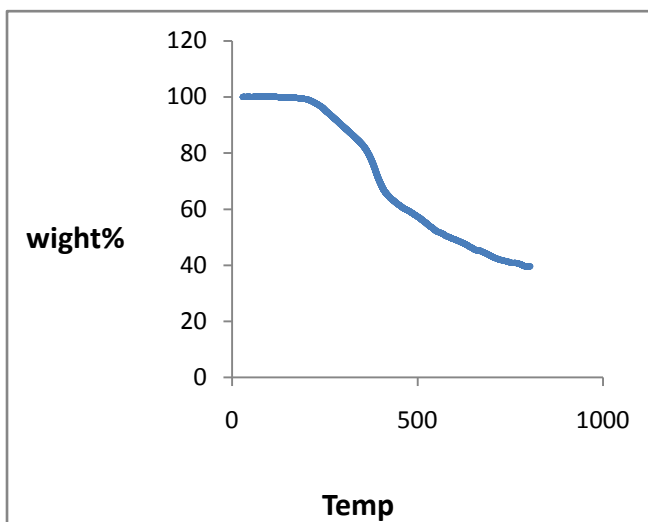


Figure-23: TGA curve of PEI2

Conclusion

The current research work, direct polycondensation was achieved by the reaction of imide containing dicarboxylic acid and several aromatic diols to prepare aromatic poly (ester-imide)s. The polycondensation resulted in the formation of polymers that has high Glass transition. The structures of polymers and monomers were affirmed by FTIR

and ^1H NMR. The polymers display good thermal characteristics and good solubility in aprotic polar solvents. Resulting poly (ester-imide)s can be used for film forming, coating material and in electric or electronic industry materials.

References

- Hajipour, A.R., Zahmatkesh, S. and Ruoho, A.E. (2008), *e-Polymers*, 050.
- Hasegawa, M., Tanaka, Y., Koseki, K. and Tominaga, A. (2006). *J. Photo-polym. Sci. Technol.* 19, 285.
- Mallakpour, S. E., Hajipour, A. R. and Khoee, S. (2000). Polymerization of 4, 4'-(hexafluoroisopropylidene)-N, N'-bis (phthaloyl-L-leucine) diacid chloride with aromatic diamines by microwave irradiation. *Journal of Polymer Science Part A: Polymer Chemistry*, 38(7), 1154-1160..
- Wutz, C. (2000). Molecular order and phase transitions in smectic poly (ester imide) s based on trimellitimide. *Polymer*, 41(13), 4957-4964.
- SHsiao, S. H. and Leu, W. T. (2004). Synthesis and properties of novel aromatic poly (esterimide) s bearing naphthalene-2, 7-diyl units. *High Performance Polymers*, 16(3), 461-479.
- Hasegawa, M., Horiuchi, M. and Wada, Y. (2007). Polyimides containing trans-1, 4-cyclohexane unit (II). Low-K and Low-CTE semi-and wholly cycloaliphatic polyimides. *High Performance Polymers*, 19(2), 175-193
- Khairou, K.S., Abdullah, M.A., Aly, K.I., Nahas, N.M. and Al-Bonian, A.M. (2009), *Arabian J. Chem.*, 2, 65–72.
- Sakthivel, P. and Kannan, P. (2004). Novel thermotropic liquid crystalline-cum-photocrosslinkable polyvanillylidene alkyl/arylphosphate esters. *Journal of Polymer Science Part A: Polymer Chemistry*, 42(20), 5215-5226.
- Hasegawa, M., and Koseki, K. (2006). Poly (ester imide) s possessing low coef-cient of thermal expansion and low water absorption. *High Performance Polymers*, 18(5), 697-717.
- Jiang, Z., Yao, H., Zhang, Z., Yang, C., Liu, Z., Tao, Y., Qin, J. and Ma, D. (2009). *Org Lett*, 11:2607–2609.
- Morikawa, A. and Ono, K. (2001). Aromatic polyimides containing p-quarterphenyl and p-sexiphenyl units. *High Performance Polymers*, 13(2), S73-S84.
- Saragi, T. P., Spehr, T., Siebert, A., Fuhrmann-Lieker, T. and Salbeck, J. (2007). Spiro compounds for organic optoelectronics. *Chemical reviews*, 107(4), 1011-1065.
- Behniafar, H., Akhlaghinia, B. and Habibian, S. (2005). Synthesis and characterization of new soluble and thermally stable poly (ester-imide) s derived from N-[3, 5-bis (N-trimellitoyl) phenyl] phthalimide and various bisphenols. *European polymer journal*, 41(5), 1071-1078.
- Han, S. I., Kim, B. S., Kang, S. W., Shirai, H. and Im, S. S. (2003). Cellular interactions and degradation of aliphatic poly (ester amide) s derived from glycine and/or 4-amino butyric acid. *Biomaterials*, 24(20), 3453-3462.
- Liaw, D. J., Fan, C. L., Lin, C. C. and Wang, K. L. (2004). Synthesis and characterization of new soluble poly (ester-imide) s containing noncoplanar 2, 2'-dimethyl-4, 4'-biphenylene unit. *Journal of applied polymer science*, 92(4), 2486-2493.
- A. Rahimi and S. Farhangzadeh (2001), *Malaysian Polymer Journal*. (10), p: 1.
- Sarma, R. J. and Baruah, J. B. (2004). Synthesis and characterization of bis-(3, 5-dimethyl-4-hydroxyphenyl)(aryl) methanes as precursor for three state indicator. *Dyes and pigments*, 61(1), 39-47.
- Sarma, R. J., and Baruah, J. B. (2005). One step synthesis of dibenzoxanthenes. *Dyes and pigments*, 64(1), 91-92.
- Faghihi, K., and Hagibeygi, M. (2007). New aromatic polyamide with azo and phosphine oxide groups in the main chain. *Turkish Journal of Chemistry*, 31(1), 65-73.
- H. Guimaraesa, M. Brioudea, P. Fiuzaa, A. Pradob, S. Boaventuraa, and M. Josea (2007) Synthesis and Characterization of New Polyesters Derived From 4, 4'-Azodibenzoic Acid, Malic Acid and Adipic Acid With Aromatic Diols. ;*Materials Research*. 10(4), P: 335-339.
- Hamilton, I. (2009), Thesis. Ph.D., University of Huddersfield