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## Synthesis, Characterization of Nano Four Arms Poly (Lactide-b-N-hydroxy ethyl acrylamide) via ATRP.

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### ABSTRACT

Four of Nano four arms, poly(Lactide-b-N-hydroxy ethyl acrylamide) were prepared by having different repeating units (10, 25, 50 and 100) from L-Lactide with same amount from N-hydroxy ethyl acrylamide. The copolymers were characterized by different spectroscopic and analytical techniques, such as FT-IR, <sup>1</sup>HNMR, <sup>13</sup>CNMR, Gel Permeation Chromatography and Scanning Electron Microscopy. The all characterization methods were confirmed the expected structure of prepared copolymers, on the other hand the prepared copolymers have a nanostructure due to the lactide fibers.

**Keywords:** Nano four arms, L-Lactide, N-hydroxy ethyl acrylamide, ATRP, nanostructure, lactide fibers

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## INTRODUCTION

The atom transfer radical polymerization was developed in 1995 independently by Kato *et al.* [1] and Wang and Matyjaszewski [2,3] as an expansion of transition metal catalyzed atom transfer radical addition, they were based on catalytic systems used for the atom transfer radical addition reaction (ATRA), an efficient method of forming carbon-carbon bonds between organic halides and alkenes.

Moreover, Matyjaszewski's team has studied the polymerization of methacrylamides using model R-haloamide based initiators, to obtain well-defined block copolymers [4]. Furthermore, chloropropionamides as an initiator was used in the polymerization of N-isopropylacrylamide monomers with small polydispersity index, to study the influence of end group functionalization on the thermal properties of polymer [5]. In this direction, Venkataraman and their colleagues have synthesized block polymer by using amino acid based initiator, due to biological relevancy, commercial availability, amphiphilic nature, and simplicity. They have used valine as the precursor for synthesis of functional initiators and synthesized poly(*tert*-butylacrylate)-*b*-polystyrene (PtBA-*b*-PS) [4] diblock copolymer [6]. Recently, a hydrolysis resistant amide-linkage heterofunctional based initiator was used in the synthesis of well-defined rod-coil block copolymers poly(N-isopropylacrylamide)-*b*-poly(L-lysine) by a combination of ATRP and amine hydrochloride mediated ring-opening polymerization (ROP) techniques [7]. In a previous work, four of four arms, poly(L-Lactide)/from pentaerythritol with L-lactide via Ring Opening Polymerization were prepared [8], while the current study include the reaction of these polymers with N-hydroxyethyl acrylamide by ATRP method to prepared well-defined copolymers.

## EXPERIMENT

**Chemicals:** 2-Bromoisobutryl bromide, N-hydroxyethyl acrylamide, Copper(I) bromide, N,N,N',N'',N'''-pentamethyldiethylenetriamine, diethyl ether and magnesium sulphate were supplied by (Sigma-Aldrich Co.), dichloromethane (DCM) (Assay  $\geq$  99.5 %) and dimethylformamide (DMF) (Assay  $\geq$  99.8 %) and Triethyl amine were supplied by (MACRON Co.).

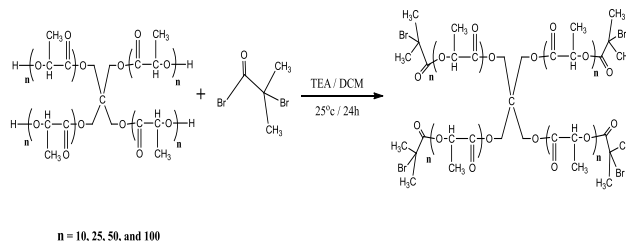
**Instruments:** The FTIR spectra were recorded using Nicolet IR-42, Mid-IR spectrometer. The viscous prepared polymers were examined using NaCl discs and the solid copolymers were characterized as KBr discs.  $^1\text{H}$  and  $^{13}\text{C}$  NMR of polymers and copolymers were recorded on Agilent DDR2 500MHz NMR spectrometers, using  $\text{CDCl}_3$  (Sigma-Aldrich, 99.8% atom D) and dimethyl sulfoxide- $d_6$  (Sigma-Aldrich, 99.9 atom % D). Polymers molecular weights and molecular weight distributions (Mw/Mn) were determined using a Waters 1515 gel permeation chromatography (GPC) equipped with a refractive-index detector (Waters 2412), DMF was used as the eluent at a flow rate of 1.0 mL/min and calibrated with poly(methyl methacrylate) standard. All the measurements were carried out at Department of Chemistry/Michigan State University. The prepared copolymers were examined under Scanning Electron Microscope type JEOL 7500F supplied by JEOL company/USA, available at the Center of Advanced Microscopy/Michigan State University.

 Preparation of ATRP initiator ( $\text{PL}_n\text{Br}$ )

Pentaerythritol-Lactide,  $\text{PL}_{10}$ , (4.528 g, 0.0015 mole) and trimethylamine, TEA, (0.84 ml, 0.006 mole) were dissolved in DCM (25ml) at  $0^\circ\text{C}$ . After stirring for 15 minutes under nitrogen atmosphere, 2-bromoisobutryl bromide (BIBB) (0.74 ml, 0.006 mole (dissolved in 5 ml DCM)) was added drop wise to the first mixed solution. The stirred reaction was kept under nitrogen in an ice-bath for 1 hour. Then reaction was stirred for a further 24 hours at room temperature. Afterwards, the product was washed with 1M HCl, saturated sodium bicarbonate and distilled water three times, then dried over magnesium sulfate and filtered; DCM was evaporated from the filtrate by rotary evaporator. The yield was about 70%. The same procedure was repeated to prepare polymers ( $\text{PL}_{25}\text{Br}$ ), ( $\text{PL}_{50}\text{Br}$ ) and ( $\text{PL}_{100}\text{Br}$ ), table 1 lists the quantities of reactants used in the preparation and the preparation rout can be represented by chemical equations shown in scheme 1 of those ATRP initiators.

 Table 1: The quantities of reactants used in the preparation of ( $\text{PL}_{25}\text{Br}$ ), ( $\text{PL}_{50}\text{Br}$ ) and ( $\text{PL}_{100}\text{Br}$ ) ATRP initiators

Polymer Code	Amount of $\text{PL}_n$		Amount of TEA		Amount of BIBB		Yield (%)
	Weight (g)	No. of moles	Volume (ml)	No. of moles	Volume (ml)	No. of moles	
$\text{PL}_{25}\text{Br}$	3.67	0.0005	0.28	0.002	0.25	0.002	73
$\text{PL}_{50}\text{Br}$	3.64	0.00025	0.14	0.001	0.13	0.001	76
$\text{PL}_{100}\text{Br}$	2.9	0.0001	0.06	0.0004	0.05	0.0004	78


 Scheme 1: Chemical equation of the preparation of ATRP Initiator  $\text{PL}_{10}\text{Br}$ ,  $\text{PL}_{25}\text{Br}$ ,  $\text{PL}_{50}\text{Br}$  and  $\text{PL}_{100}\text{Br}$ 

 Preparation of four arms Poly(Lactide-*b*-N-hydroxy ethyl acrylamide)( $\text{PL}_n\text{BrN}_m$ )

Pentaerythritol-lactide bromide ( $\text{PL}_n\text{Br}$ ) (0.4 g, 0.00011 mole), N-hydroxy ethyl acrylamide (HEA) (0.8 g, 0.007 mole), Copper(I) bromide (0.05 g) and N,N,N',N'',N'''-Pentamethyldiethylenetriamine (PMDETA) (20  $\mu\text{l}$ ) were dissolved in dimethyl formamide (DMF) (15ml) at  $60^\circ\text{C}$ . After stirring for 1h under nitrogen atmosphere, the reaction was stirred for a further 14 hours at  $60^\circ\text{C}$ , afterwards, the product was added slowly to 500 ml cold diethyl ether to precipitate the copolymer which was then filtered on a Buchner funnel and washed with diethyl ether, and then the filtrate was dissolved in DMF (15ml). The copolymer was recovered through the silica gel column chromatography, DMF was removed by rotary evaporator and the copolymer was dried in vacuum oven at  $25^\circ\text{C}$  for 24 hours, (Yield 70%). The same procedure was carried out to prepare the copolymers ( $\text{PL}_{25}\text{BrN}_m$ ), ( $\text{PL}_{50}\text{BrN}_m$ ) and ( $\text{PL}_{100}\text{BrN}_m$ ), table 2 illustrates shows the quantities of reactants used in the preparation and the chemical equations of prepared copolymers are shown in the scheme 2.

 Table 2: The quantities of reactants used in the preparation of ( $\text{PL}_{25}\text{BrN}_m$ ), ( $\text{PL}_{50}\text{BrN}_m$ ) and ( $\text{PL}_{100}\text{BrN}_m$ ) copolymers, where  $n = 10, 25, 50$  and  $100$ 

Copolymer Code	Amount of $\text{PL}_n\text{Br}$		Amount of HEA		Wt. of CuBr (g)	Volume of PMDETA ( $\mu\text{l}$ )	Yield (%)
	Weight (g)	No. of Moles	Weight (g)	No. of Moles			
$\text{PL}_{25}\text{BrN}_m$	0.4	0.00005	0.8	0.007	0.05	20	69
$\text{PL}_{50}\text{BrN}_m$	0.4	0.00003	0.8	0.007	0.05	20	72
$\text{PL}_{100}\text{BrN}_m$	0.4	0.00001	0.8	0.007	0.05	20	71

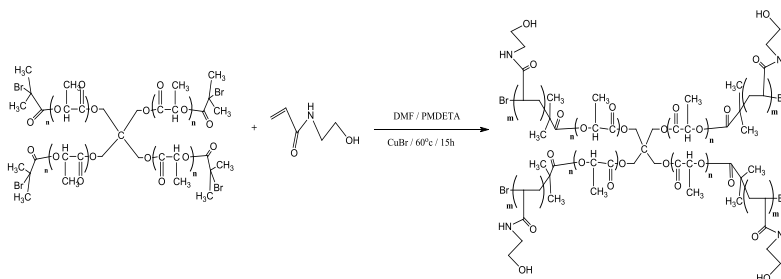

 Scheme 2: Chemical equation of the preparation of ATRP Initiator  $\text{PL}_{10}\text{Br}$ ,  $\text{PL}_{25}\text{Br}$ ,  $\text{PL}_{50}\text{Br}$  and  $\text{PL}_{100}\text{Br}$

Table 3: GPC results for prepared copolymers

No.	Polymer Name	CalculatedMn (Daltons)	FoundMn (Daltons)	Found Mw (Daltons)	PDI
1	PL10BrNm	12	9126	10347	1.13
2	PL25BrNm	29	21264	23815	1.12
3	PL50BrNm	59	42266	43383	1.03
4	PL100BrNm	113	81502	87810	1.08

RESULTS AND DISCUSSION

Characterization of prepared ATRP initiators and copolymers by FT-IR

The spectra of prepared ATRP initiators (PL<sub>10</sub>Br, PL<sub>25</sub>Br, PL<sub>50</sub>Br and PL<sub>100</sub>Br) polymers exhibited an intense new characteristic absorption bands at (649, 647, 641 and 635) cm<sup>-1</sup> respectively assigned to the C-Br bonds, figures 1, and the disappearing of hydroxyl groups at 3506-3517 cm<sup>-1</sup>, besides the presence of other stretching bands obtained from pentaerythritol-lactide polymers (PL<sub>10</sub>, PL<sub>25</sub>, PL<sub>50</sub> and PL<sub>100</sub>) used to prepare the ATRP initiators as discussed in the previous work [8]. The copolymers (PL<sub>10</sub>BrNm, PL<sub>25</sub>BrNm, PL<sub>50</sub>BrNm and PL<sub>100</sub>BrNm) obtained by ATRP copolymerization of PL<sub>n</sub>Br having different L-lactide chain length with N-hydroxyethyl acrylamide showed intense bands due to the associated hydroxyl groups (3384, 3310, 3315, 3325) cm<sup>-1</sup> and bands at (3115, 3080, 3079, 3081) cm<sup>-1</sup> respectively, figure 2.

Characterization of new copolymer by NMR

<sup>1</sup>HNMR spectra of prepared ATRP initiators, figure 3, showed a peak (a) at 5.3 ppm assigned for the two protons in (CH<sub>2</sub>) group of pentaerythritol. The peaks (b) at about 5.2 ppm represented the (CH) protons of repeating unit of L-lactide segments and at about 1.6 ppm (c) represent the (CH<sub>3</sub>) protons of the repeating unit. The most significant peak appears at 1.9 ppm (d) assigned for the new methyl protons of the identical two (CH<sub>3</sub>) end chain groups of bromoisobutyryl at 1.9 ppm implying the preparation of Pentaerythritol-Lactide Bromide ATRP initiators from Pentaerythritol-Lactide. This was confirmed by the disappearance of the peaks at 2.9 ppm and at 1.5 ppm assigned for hydroxyl groups at the end chains of polymers and for the (CH<sub>3</sub>) protons of a terminal molecule of L-lactide respectively [8]. ATRP copolymerization of PL<sub>n</sub>Br having different lactide chain length with N-hydroxyethyl acrylamide showed a peak at around 8.2 ppm (g) assigned to the NH group, and peaks at 3.2 ppm and 3.4 ppm (h & i) represent the methylene protons (CH<sub>2</sub>) of hydroxyethylacrylamide while the peak at 3.35 ppm (j) assigned to the proton of terminated hydroxyl groups, the protons of (CH<sub>2</sub>) and (CH) groups of N-hydroxyethyl acrylamide repeating unit were appear at around 2.55 (e) and 4.7 ppm (f) respectively, figure 4.

The <sup>13</sup>C NMR technique was also performed to confirm the structure of all the new prepared polymers and copolymers.

Figure 5 shows the <sup>13</sup>C NMR spectra of ATRP initiator (PL<sub>10</sub>Br, PL<sub>25</sub>Br, PL<sub>50</sub>Br and PL<sub>100</sub>Br) polymers. They exhibit a peak at 168 ppm (f) assigned to the carbon atom of last carbonyl groups of isobutyryl bromide, the peak at 55 ppm (g) assigned to the tertiary carbon atom bonded to bromide atom. The peak appears at 30 ppm (h) represented the carbon atom in the last dimethyl group at the end chains. The others peaks (a, b, c, d and e) are generated from Pentaerythritol-Lactide and appears in their usual ppm as before their reaction with isobutyryl bromide [8]. Copolymerization of PL<sub>x</sub> polymers with N-hydroxyethyl acrylamide was also confirmed by <sup>13</sup>C NMR, figure 6, due to the peaks is appeared at 42 ppm (i) and at 49 ppm (j) were assigned for the carbon of (CH<sub>2</sub>) and (CH) groups in repeating unit of N-hydroxyethyl acrylamide respectively and a peak at about 170 ppm (k) for its carbonyl carbon atom. While the carbon atom in (CH<sub>2</sub>) groups in branched part of N-hydroxyethylacrylamide (l and m) were appeared at around 40 ppm and 60 ppm respectively.

Determination of polydispersity index by Gel Permeation Chromatography (GPC)

The molecular weight distributions (Mw/Mn) were calculated for all prepared copolymers and table 3 shows the GPC results. It appears that the PDI is ranging between 1.03-1.13 indicating that the copolymers molecular weight distribution is nearly monodispers or from narrow distribution type. All these results are confirmed the expected structure and composition of the prepared polymers and promoted this matter with great accuracy the results of GPC as shown significant closely with theoretical calculations of molecular weight and result the awesome polydispersity index (PDI) is close to one.

Characterization of Nano structures by Scanning Electron Microscopy

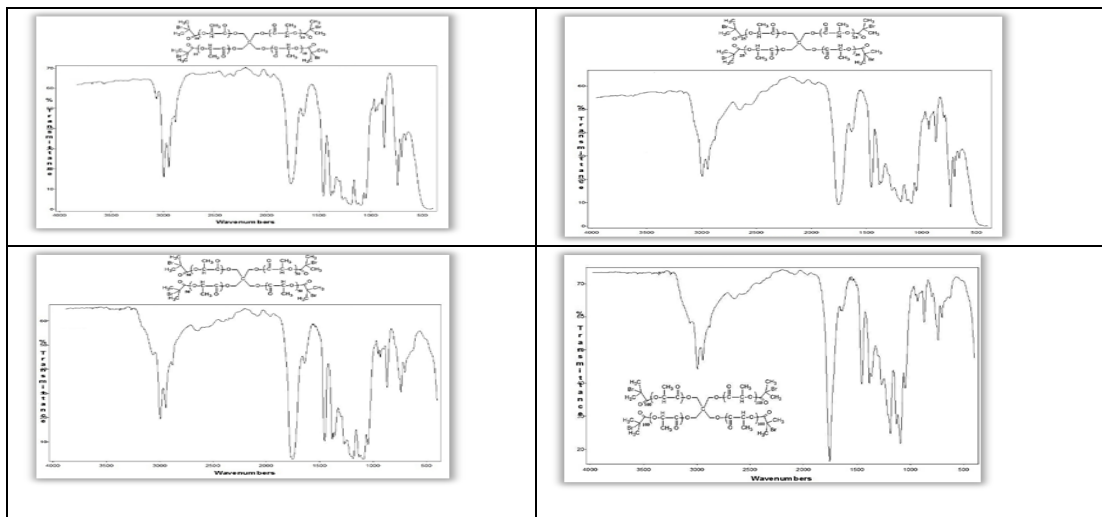
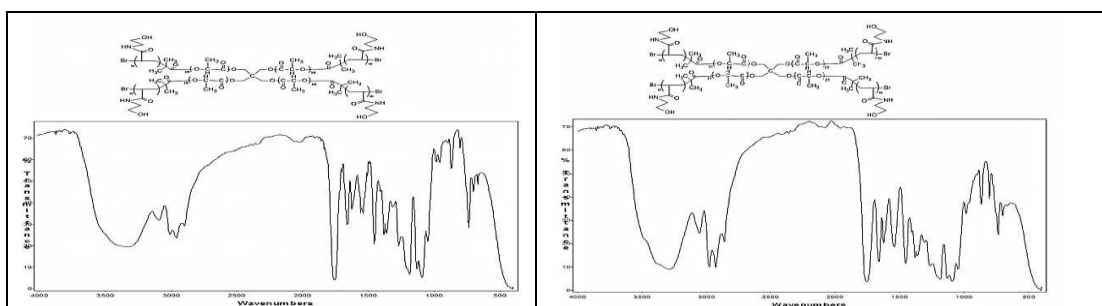


Figure 1: FT-IR spectra of (PL<sub>10</sub>Br, PL<sub>25</sub>Br, PL<sub>50</sub>Br and PL<sub>100</sub>Br)



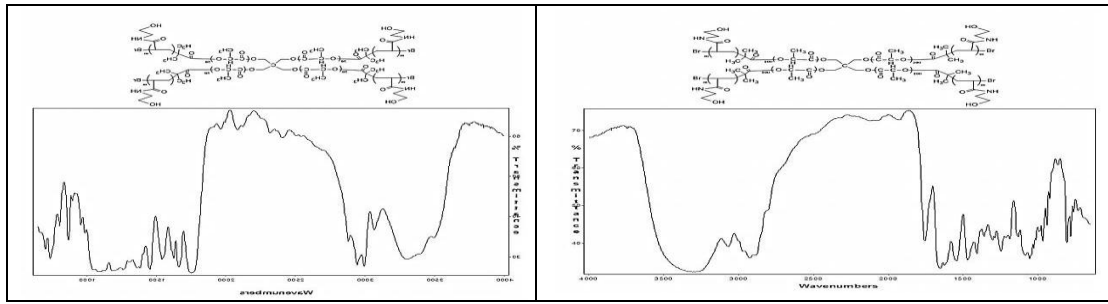


Figure 2: FT-IR spectra of (PL<sub>10</sub>BrNm, PL<sub>25</sub>BrNm, PL<sub>50</sub>BrNm and PL<sub>100</sub>BrNm)

The examination of the morphology and fiber geometry of the copolymers was performed by using SEM at different amplifications (10 μm and 100 nm). Figures (7-8) show the SEM micrographs of examining copolymers. The micrographs obtained from scanning electron microscope were exhibited the size of the nanoparticles, and it was found to be in a range of (27.6-86.3) nm and the images of SEM measurements showed the size of the nanoparticles decreased with increasing the chain length of monomers in copolymers.

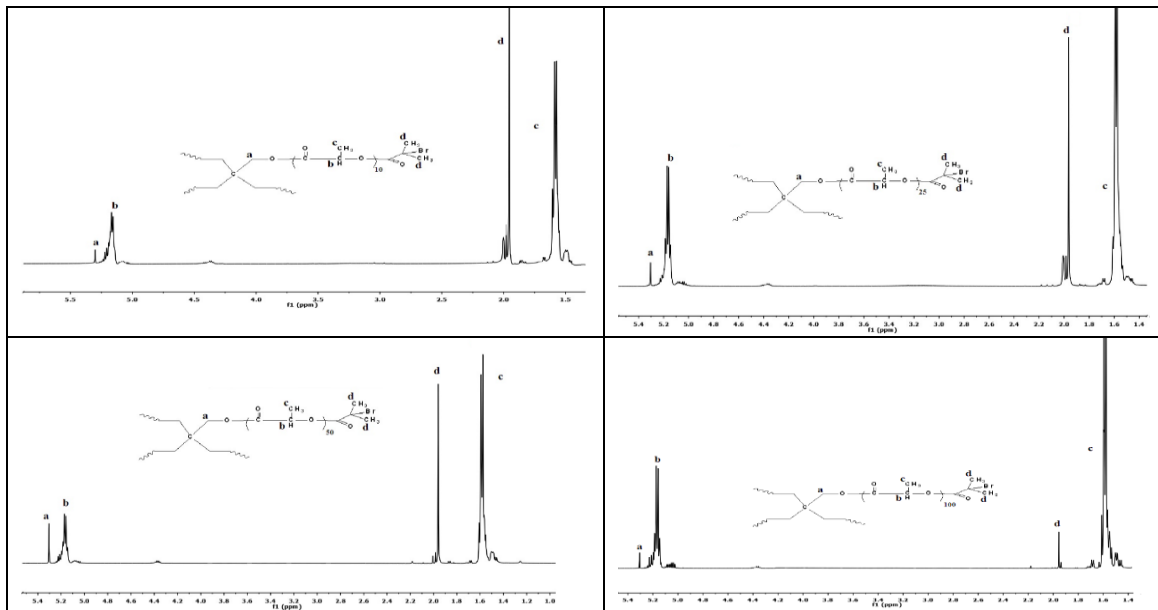


Figure 3: <sup>1</sup>H NMR spectra of (PL<sub>10</sub>Br, PL<sub>25</sub>Br, PL<sub>50</sub>Br and PL<sub>100</sub>Br)

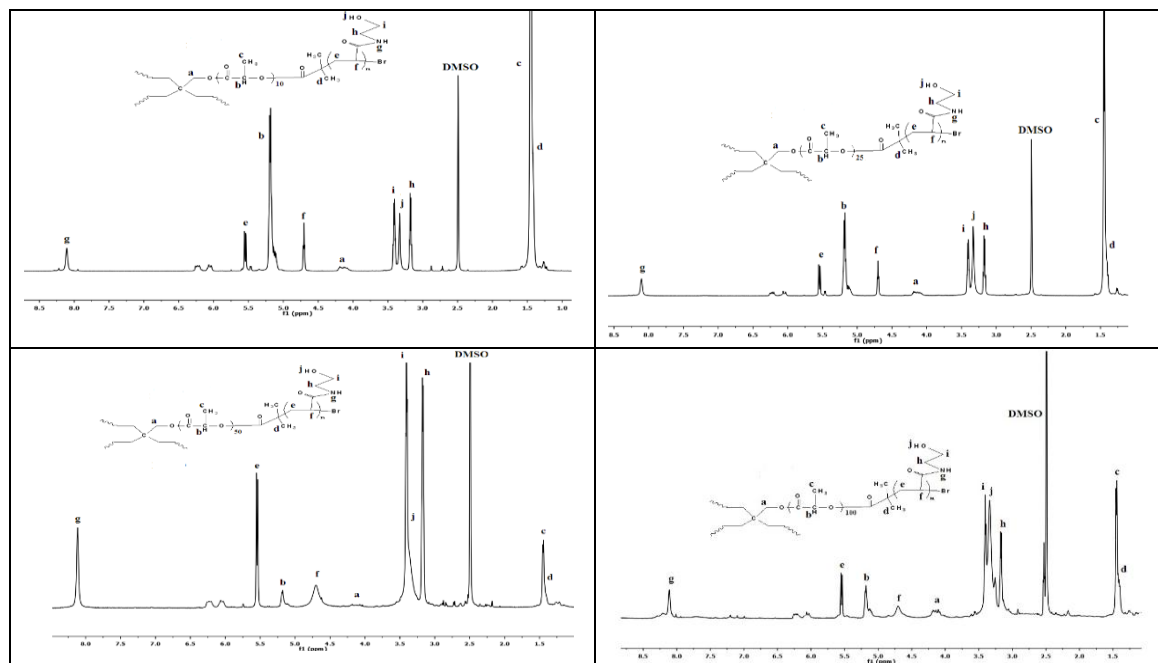


Figure 4: <sup>1</sup>H NMR spectra of (PL<sub>10</sub>BrNm, PL<sub>25</sub>BrNm, PL<sub>50</sub>BrNm and PL<sub>100</sub>BrNm)

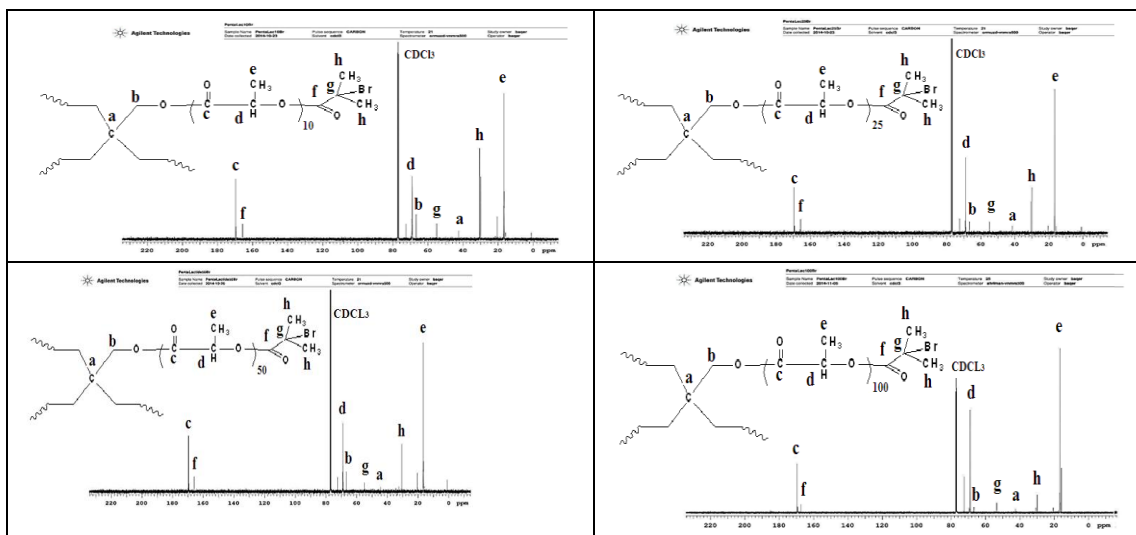


Figure 5: <sup>13</sup>C NMR spectra of (PL<sub>10</sub>Br, PL<sub>25</sub>Br, PL<sub>50</sub>Br and PL<sub>100</sub>Br)

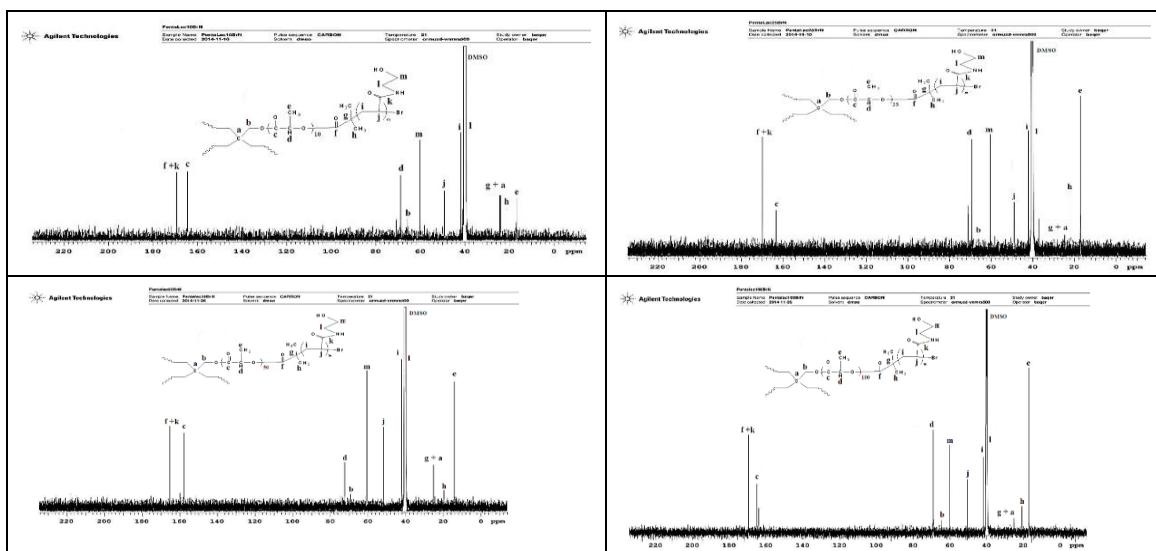


Figure 6: <sup>13</sup>C NMR spectra of (PL<sub>10</sub>Br<sub>n</sub>, PL<sub>25</sub>Br<sub>n</sub>, PL<sub>50</sub>Br<sub>n</sub> and PL<sub>100</sub>Br<sub>n</sub>)

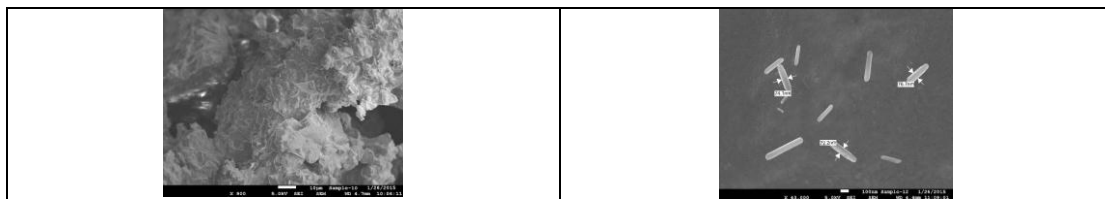


Figure 7: SEM micrographs of PL<sub>25</sub>Br<sub>n</sub>

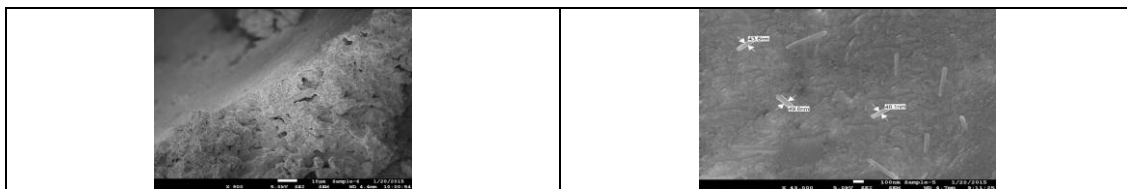


Figure 8: SEM micrographs of PL<sub>100</sub>Br<sub>n</sub>

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