Copolymerization Parameters of 2-(N-Phthalimido) ethyl Methacrylate with Different Vinyl Monomers

A.A. KHALIL, A.A. ALY and H.M. AMMAR

Department of Chemistry, Faculty of Science, Benha University, Benha (Egypt).

ABSTRACT

2-(N-phthalimido)ethyl methacrylate was prepared by the reaction of methacrylic acid with N-(2-hydroxyethyl)phthalimide in presence of N,N'-dicyclohexylcarbodiimide. The monomer reactivity ratios for copolymerization reactions of 2-(N-phthalimido)ethyl methacrylate with methyl acrylate, ethyl acrylate, butyl acrylate and styrene, respectively, in solution with azobisisobutyronitrile (AIBN) as initiator, were estimated by nitrogen analysis. The structure of the copolymers was investigated by IR spectroscopy. The Q and e values for 2-(N-phthalimido)ethyl methacrylate were calculated. Some of the synthesized polymers were tested for their antimicrobial activity against bacteria and fungi.

Key words: N-(2-Hydroxyethyl)phthalimide, 2-(N-phthalimido)ethyl methacrylate, methacrylic acid, copolymerization reactions and dicycloheylcarbodiimide.

INTRODUCTION

Copolymerization is one of the most important means to improve the performance of polymers. Since polymers are generally immiscible due to adverse entropy effects, copolymerization offers a convenient method of incorporating different monomers in polymer chain. The difficulties associated with the synthesis of copolymers are the wide variation in the reactivity ratios of the monomers[1,2]. Reactivity ratios are among the most important parameters for the composition equation of copolymers, which can offer information such as the relative reactivity of monomer pairs and help estimate the copolymer composition[3]. To calculate the polymerization rate or polymer productivity and copolymer composition, monomer reactivity ratios must be known. The method which is used most often nowadays for estimating monomer reactivity ratios is to perform a low conversion copolymerization at various initial monomers feed compositions. Subsequently, the copolymer composition is determined for each reaction[4]. Reactivity ratio values may be evaluated by various procedures[5–8].

Aromatic polyimides have become an important class of polymers that have a wide range of application as high performance materials in the aerospace and industries electronics because of high thermal stability[9-13]. Aromatic polyimide having phthalimide pendent group into the polymer are found to possess excellent heat resistance, transparency and enhances the solubility and thermal stability of polymer[14,15].

Phthalimide and its derivatives are very important compounds. They used in the synthesis of antimicrobial activity, antiandrogens and other agents for treating tumour necrosis factor. Certain phthalimide derivatives are used as herbicides and for reducing bacterial contamination[16]. Copolymers containing the phthalimide derivatives have been used as optical brightening agents[17]. N-Substituted phthalimide copolymers may be used as activated drug binding materials[18].

In our previous work we described the synthesis, polymerization, copolymerization and exchange reactions of the acrylic and methacrylic

esters of N-hydroxyphthalimide and N-hydroxytetrabromophthalimide [19-24]. The aim of the present work is to report the synthesis, characterization and determination of reactivity ratios for copolymerizations of 2-(N-phthalimido)ethyl methacrylate (PEMA) with methyl acrylate (MA), ethyl acrylate (EA), butyl acrylate (BA) and styrene (ST).

EXPERIMENTAL

Materials

Methyl acrylate, ethyl acrylate, butyl acrylate and styrene were BDH (England) products. Phthalic anhydride and N,N-dicyclohexylcarbodiimide (DCCI) were from Aldrich Co.. Methacrylic acid and the free radical initiator, azobisisobutyronitril (AIBN), were from E. Merck, Darmstadt. All the solvents were of reagent grade and were purified by distillation before use.

Synthesis
1-Preparation of N-(2-hydroxyethyl) phthalimide (NHEP)

Phthalic anhydride (0.1 Mol) was taken in a two-necked flask fitted with a reflux condenser and a nitrogen inlet, and dissolved in 50 ml of DMF, 0.1 mol of ethanolamine was added dropwise to it. The reaction was moderately exothermic hence cooled in an ice bath. The contents were stirred with magnetic stirrer and heated in an oil bath to 130°C in nitrogen atmosphere for 3 h. Excess DMF was removed by vacuum distillation and the contents were poured into water. The precipitated product, NHEP, was filtered off and recrystallised using ethanol as a solvent. The yield was 75% and m.p. was 125-127°C. (Lit.126)[25]

2-Synthesis of 2-(N-phthalimido)ethyl methacrylate (PEMA)

To a cold solution (0–5°C) of 19.1 g (0.1 mol) of N-(2-hydroxyethyl) phthalimide (NHEP) and 8.6 g (0.1mol) of methacrylic acid in ethyl methyl ketone (100 ml) was added 20.6 g of DCCI, with stirring. After stirring for 6 h at room temperature, the precipitated dicyclohexyl urea was removed by filtration and the filtrate was evaporated to dryness in vacuum. 2-(N-Phthalimido)ethyl methacrylate (PEMA), obtained as a white solid, was washed with 0.05% NaOH and recrystallised from ethanol, the

yield was 70%, m.p. 75-77°C (Lit.75°C)[25].

Homopolymerization

Solution (10%) of the monomer in DMF was treated with azobisisobutyronitrile (AIBN) (1mol%). After purging with deoxygenated nitrogen, the reaction mixture was allowed to stand at 60°C for 6h. The polymer was obtained by reprecipitation in methanol and were collected by filtration, washed dried and weighted. The yield was 80%.

Copolymerization reactions

Copolymers of 2-(N-phthalimido)ethyl methacrylate (PEMA) with methyl acrylate, ethyl acrylate, butyl acrylate and styrene were studied for different mole fractions in the feed. The reaction time was restricted to give conversion less than 10% in order to obtained polymer samples with homogeneous composition.

The copolymers were obtained by solution polymerization method in presence of azobisisobutronitrile (AIBN) as a free radical initiator. Thus the pre-determined amounts of the comonomers were placed in glass tubes, and diluted with dimethyl formamide so that the total monomer composition was about (1.5mol/l). Polymerization was commenced by adding AIBN (1mol%). The tubes were flushed with oxygen-free nitrogen for 10 minutes, capped and thermostated at 65⁰C for 1-3h, depending on the comonomer pairs and composition. All copolymers were obtained by reprecipitation from methanol, except EA reprecipitation from 50% methanol and 50% distilled water and all washed several times, dried and weighed. The composition of copolymers was determined from nitrogen analysis.

Characterization

IR spectra were recorded (KBr) on a Pye-Unicam Sp-883 Perkin Elmer spectrophotometer. ^{1}HNMR spectra were recorded on a Varian Gemini 200 MHz spectrophotometer, Cairo University. The chemical shift (δ) are given downfield relative to tetramethylsilian (TMS) as the internal standard. The elemental analysis were also carried out in Microanalytical center, Cairo University. The antibacterial and antifungal activities were carried out at the Regional Centre for Mycology, and

Biotechnology at Microanalyticl Center, Cairo University.

RESULTS AND DISCUSSION

In the present investigation, 2-(N-phthalimido)ethyl methacrylate (PEMA) was prepared by the reaction of N-(2-hydroxyethyl) phthalimide (NHEP) with methacrylic acid in the presence of DCCI, according to the following (Scheme1):
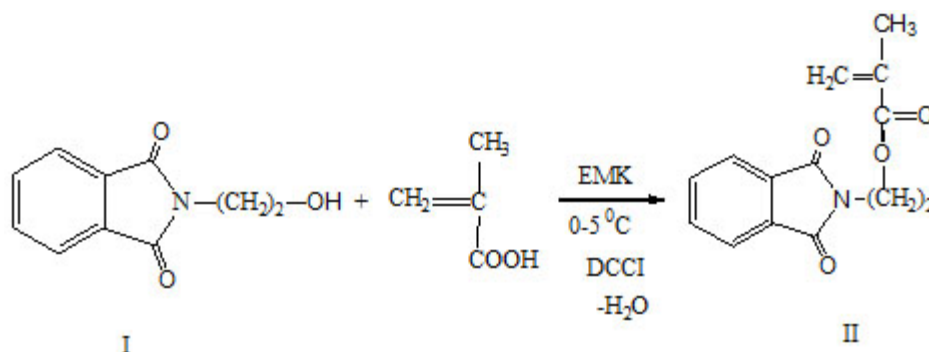
(Scheme 1)

The monomer was a crystalline solid, easily soluble in most organic solvents, but sparingly soluble in aliphatic hydrocarbons, such as n-hexane and petroleum ether.

The structure of PEMA monomer was confirmed by IR and ^{1}HNMR spectroscopy.

IR (cm^{-1}): 3100, (aromatic C-H stretching), 3062 (olefinic C-H stretching), 2930 and 2857 (symmetrical and asymmetrical C-H stretching due to CH$_2$ and CH$_3$), 1770 (-CO-OR), 1720 (C=0 stretching due to phthalimido group), 1640 (olefinic C=C stretching).

^{1}HNMR (ppm): 7.95-7.74 (aromatic protons), 6.02 and 5.53 (2H) [olefinic protons], 4.41 (2H) [-CH2-O], 4.01 (2H) [$>$N-CH2] and 1.45 (3H) [Methyl]

The copolymerization of PEMA with MA, EA, BA and ST were studied and the reaction can be written as shown in (Scheme 2).
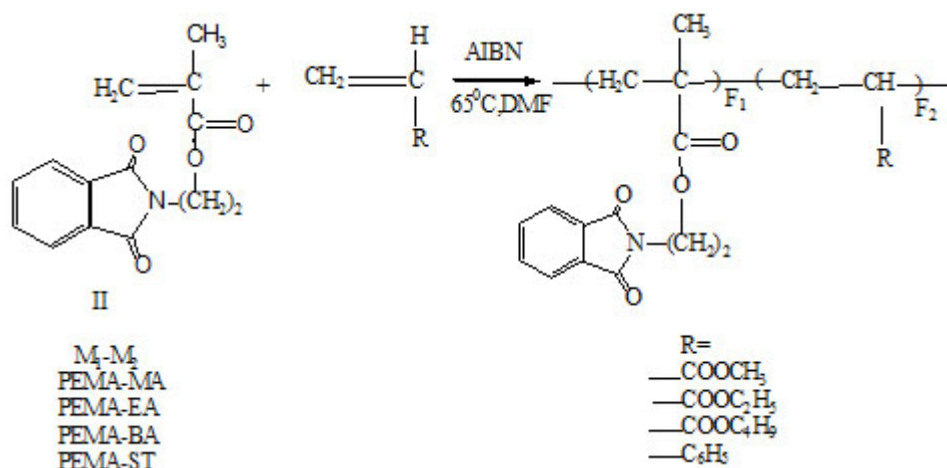
Scheme 2.

Table 1: Copolymerization of (PEMA) with (MA)

Monomer composition		Conversion	N(%)	Copolymer composition	
a	f_1^0	weight(%)		b	F_1^0
0.2500	0.2	9.5	3.85	0.822	0.45
0.4286	0.3	8.8	4.47	1.587	0.613
0.6667	0.4	9.1	4.56	1.791	0.641
1.000	0.5	7.11	2.178	2.178	0.69
1.500	0.6	9.4	4.90	3.2	0.76

a: M_1/M_2 in feed composition

f_1: mole fraction of M_1 in feed composition

b: m_1/m_2 in copolymer composition

F_1: mole fraction of m_1 in copolymer composition

Table 2: Copolymerization of PEMA with (EA)

Monomer composition		Conversion	N(%)	Copolymer composition	
a	f_1^0	weight(%)		b	F_1^0
0.111	0.1	9.1	1.54	0.154	0.17
0.25	0.2	7.5	2.8	0.41	0. 3
0.428	0.3	8.6	3.78	0.89	0.46
0.666	0.4	5.5	4.27	1.48	0.56
1.00	0.5	9.7	4.6	2.2	0.71

Table 3: Copolymerization of PEMA with (BA)

Monomer composition		Conversion	N(%)	Copolymer composition	
a	f_1^0	weight(%)		b	F_1^0
0.111	0.1	5.7	0.75	0.079	0.076
0.25	0.2	9.6	1.6	0.208	0. 16
0.428	0.3	7.5	2.13	0.322	0.25
0.666	0.4	5.4	2.86	0.560	0.35
1.00	0.5	9.5	3.42	0.850	0.46

Table 4: Copolymerization of PEMA with (ST)

Monomer composition		Conversion	N(%)	Copolymer composition	
a	f_1^0	weight(%)		b	F_1^0
0.111	0.1	8.8	0.94	0.0847	0.078
0.25	0.2	9.6	1.56	0.1631	0. 1402
0.428	0.3	5.8	2.18	0.271	0.217
0.666	0.4	7.9	2.96	0.4725	0.32
1.5	0.6	8.5	4.12	1.289	0.56

In all systems studied, the composition of each copolymer was calculated from its nitrogen content. The structure of the copolymers was confirmed by IR spectroscopy. The IR spectrum of PEMA-ST copolymer, as example, shows peak at 3030 cm⁻¹ is due to the C-H stretching of aromatic protons. Peaks at 2929 and 2858 cm⁻¹ corresponding to the C-H stretching of methyl and methylene groups. The strong absorption peaks at 1770 and 1750 cm⁻¹ are due to the ester carbonyl stretching and that at 1732 cm⁻¹ is due to the carbonyl stretching of the phthalimido group and a strong band at 760 cm⁻¹ due to monosubstituted benzene ring.

For the industrial preparation of any copolymers, knowledge of reactivity ratio is very essential. The reactivity ratios of PEMA with MA, EA, BA and ST were evaluated from the monomer feed ratios and the copolymer composition.

Tables (1-4) illustrate the analytical data for copolymerization reactions of PEMA with MA, EA, BA and ST. From the values of feed and copolymer composition, the monomer reactivity ratios (r_1 and r_2) for each system were evaluated using Fineman –Ross[27] and Kelen–Tudos[28] methods and the standard deviations of the results were calculated by regression analysis as given in Table

Table 5: Monomer reactivity ratios for copolymerization of PEMA with MA, EA, BA and ST

M_1-M_2	Fineman-Ross method		Kelen-Tudos method			R1r2
	r1	r2	r1	r2	α	
PEMA-MA	1.53±0.135	0.1039±0.05	1.49±0.35	0.099±0.05	0.231	0.147
PEMA-EA	3.18±0.135	0.826±0.135	3.4±0.35	0.826±0.05	0.19	2.8
PEMA-BA	1.04±0.17	1.399±0.12	1.1±0.08	1.41±0.07	0.428	1.55
PEMA-ST	0.93±0.115	1.624±0.109	0.83±0.114	1.6±0.13	0.505	1.32

Table 6: Antimicrobial activity of some synthesized compounds

Compound	Bacteria		Fungi	
	Staphylococcus aureus	*Escherichia coli*	*Aspergillus flavus*	*Candida albicans*
PEMA	12	11	-	12
poly(PEMA)	11	11	-	-
poly(PEMA -co-St)(0.1:0.9)	-	-	-	-
poly(PEMA -co-St)(0.3:0.7)	-	-	-	-
poly(PEMA-co-St)(0.6:0.4)	10	-	-	9
poly(PEMA -co-BA) (0.1:0.9)	-	-	-	-
poly(PEMA -co-BA) (0.5:0.5)	-	9	-	-
poly(PEMA -co-EA) (0.1:0.9)	-	9	-	-
poly(PEMA -co-EA) (0.5:0.5)	12	12	-	14
poly(PEMA -co-MA) (0.2:0.8)	13	13	-	10
poly(PEMA -co-MA) (0.3:0.7)	11	13		
poly(PEMA -co-MA) (0.4:0.6)	-	-	-	9
Tetracyclin	30	33		
Amphotericin B			19	20

(5). Fig. (1) shows the Kelen–Tudos[28] plots for the four systems studied. The values of r_1 and r_2 obtained by Fineman–Ross and Kelen– Tudos are almost identical. The r_1r_2 value for PEMA-MA (0.15) indicates that the copolymer should have a random distribution of the monomer units, while for the PEMA-EA, PEMA-BA and PEMA-ST systems the r_1r_2 values (2.5, 1.5 and 1.32) respectively, illustrate a low tendency of monomers to alternated, and the copolymer should be composed mainly of small sequences of monomeric units of the same type.

The composition curves of the four binary copolymerization reactions studied are illustrated in Fig. (2) which indicates that all studied systems gave no azeotropic compositions.

The Q and e values were calculated by using the Alfrey-Price equations[29]

$$e_1 = e_2 \pm (-\ln r_1 r_2)^{1/2},$$

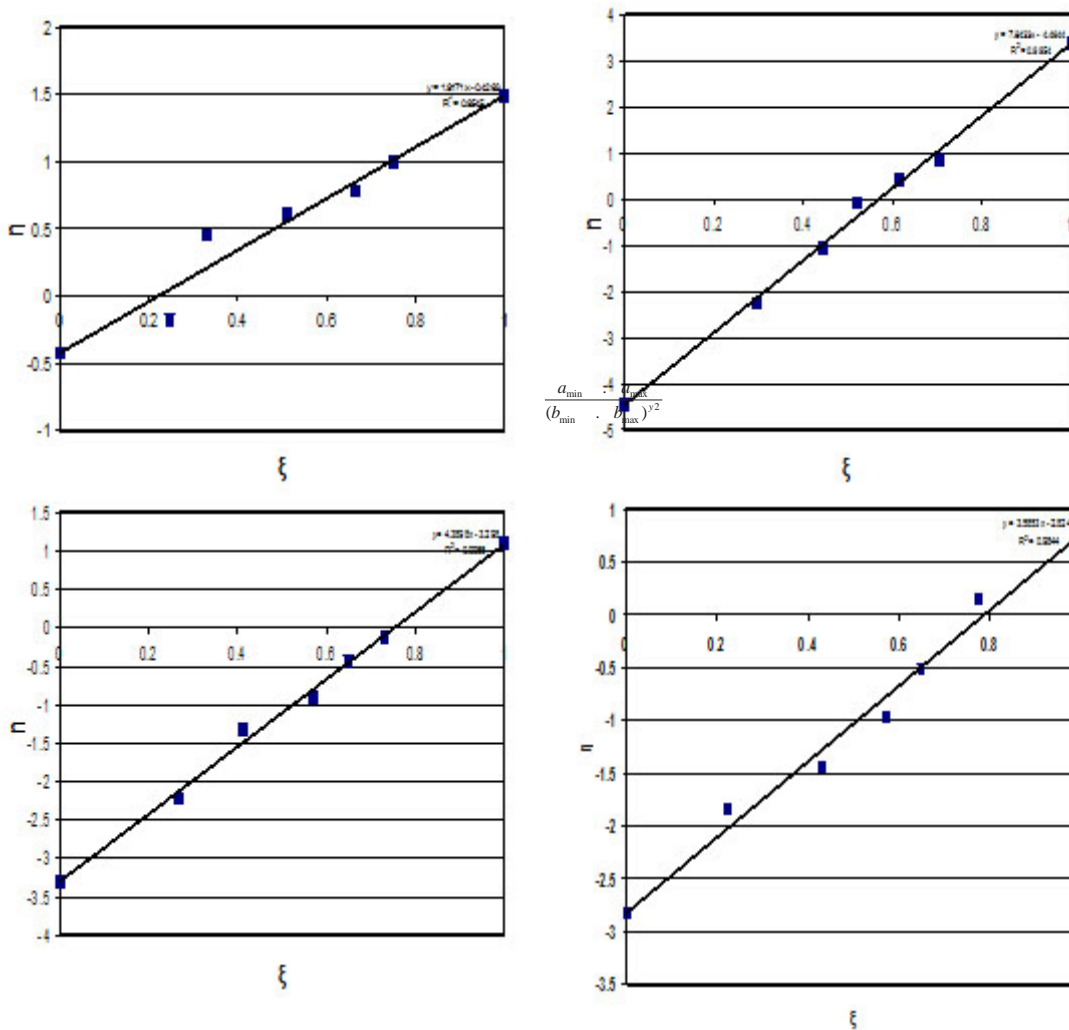$$Q_1 = (Q_2 / r_2) \exp[-e_2(e_2 - e_1)]$$

Fig. 1. Kelen-Tudos plots for copolymerizations of PEMA with: (a)MA, (b)EA, (c)BA and (d) ST : $\zeta = \dfrac{a_2}{\alpha b + a_2}$ *and* $\eta = \dfrac{a(b-1)}{\alpha b + a_2}$ **where a and b are the molar ratios (M_1/M_2)**

of the comonomer in the feed and copolymer, respectively, and $\alpha =$

The Q and e values which represent the extent of resonance stabilization and the polarity of the double bond, respectively, in a monomer and its radical are extensively tabulated by Young[30] from earlier copolymerization data. Thus, the average Q and e values for PEMA were obtained by using the monomer reactivity ratios determined for the copolymer systems and using the Q and e values for the vinyl monomers. The average Q and e values for NPEMA were found to be Q =1.4 and e = 0.51 and are in agreement with those reported in the literature[30] for the esters of methacrylic acid.

Antimicrobial activity

The antimicrobial activity of the synthesized compounds was determined *in vitro* using the hole plate and filter paper method[24] against a variety of bacteria and fungi. Comparative studies of our prepared compounds and standard drug were also carried out . The tested compounds were dissolved in DMSO, different concentration have been chosen (125, 250 and 500 µg/ml). The inhibition zones of microbial growth produced by different compounds were measured in millimeters at the end of an incubation period of 48h at 28°C. DMSO alone showed no inhibition zone. The gram +ve bacteria were Staphylococcus aureus; the gram –ve bacteria were Escherichia coli and the fungi were Aspergillus flavus and Candida albicans. Tetracyclin and Amphotericin B were used as
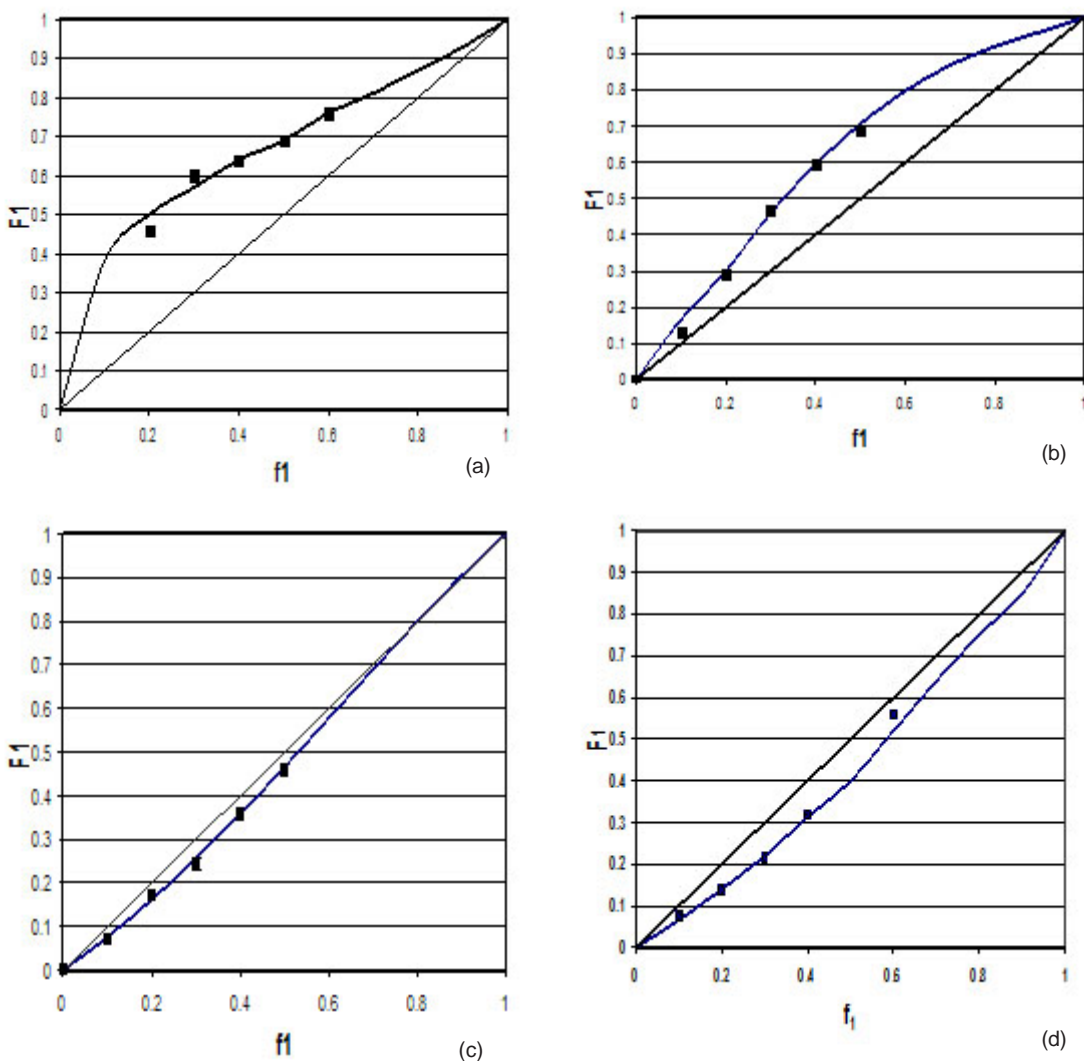

Fig. 2: Composition curves for copolymerization of PEMA with: (a)MA, (b)EA, (c)BA and (d)ST

standard for antibacterial and antifungal activity, respectively. The results are illustrated in (Table 6).

CONCLUSION

Copolymers from PEMA with MA, EA, BA and ST with different compositions were easily synthesized in DMF by free radical polymerization. The monomer reactivity ratios (r_1 and r_2) for each system were evaluated using Fineman –Ross and Kelen–Tudos methods and the values obtained are in good agreement. The r_1r_2 value for PEMA-MA

(0.15) indicates that the copolymer should have a random distribution of the monomer units, while for the PEMA-EA, PEMA-BA and PEMA-ST systems the r_1r_2 values (2.5, 1.5 and 1.32) respectively illustrate a low tendency of monomers to alternated, and the copolymer should be composed mainly of small sequences of monomeric units of the same type. The composition curves indicates that all studied systems gave no azeotropic compositions. The average Q and e values for PEMA are in agreement with those reported in the literature for the esters of methacrylic acid.

REFERENCES

1. Liu, G.; Zhang, L.; Wang, Y.; Zhao, P. *J Appl Polym Sci* **114**: 3939 (2009).
2. Saby-Dubreuil, A. C.; Guerrier, B.; Allain, C. *Polymer*, **42**: 1383 (2001).
3. Erol, I.; Sen, O.; Dedelioglu, A.; Cifci, C. *J Appl Polym Sci*, **114**: 3351 (2009).
4. Habibi, A.; Farahani, E.V.; Semsarzadeh, M.A.; Sadaghiani, K. *Polym. Int*, **52**: 1434 (2003).
5. Hou, C.; Ji, C.; Ying, L. *J Appl Polym Sci* , **103**: 3920 (2007).
6. Miller, A.; Szafko, J.; Turska, E. *J. Polym. Sci.*, **15**: 51 (1977).
7. Bajaj, P.; Sen, K.; Hajir, B.S. *J Appl Polym Sci,* **59**: 1539 (1996).
8. Soykan, C.; Coskun, M.; Ahmedzade, M. *Polym. Int.*, **49**: 479 (2000).
9. Cassidy, P. E.; Marcel &Dekker, New York, 94-103 (1980).
10. Yang, H.H.; Wiley, New York, 63-98 (1989).
11. Mittal K.L.; New York, I & II, 63-67 (1984).
12. Ye, Y.S.; Yen Y.C.; Chen W.Y.; Cheng C.C.; Chang F.C.; *J Polym Sci Part A: Polym Chem*, **46**: 6296 (2008).
13. Rubehn, B.; Stieglitz T. *Biomaterials*, **31**: 3449 (2010).
14. Payene, H.F.; New York: Wiley; *Biomaterials*, **1**: 27 (1964).
15. Marton, O.R.; New York: Reinhold, "Technology of paints, varnishes and lacquers" **32**: 32 (1968).
16. Krishnakumar, A.; Balachandran, V.B.; Chithambarathanu, T.; Spectrochimica Acta Part A., **62**: 918 (2005).
17. Constantinova, T.N.; Garbechev, I.K., *Polym Int* **43**: 39 (1998).
18. Ismail, M; Veena, V.; Animesh, K.R.; *J Appl Polym Sci,* **68**: 217 (1998).
19. Shaaban, A. F.; Arief, M. M. H.; Khalil, A. A.; Messiha, N. N., *Acta Polym* **39**: 145 (1988).
20. Shaaban, A. F.; Khalil, A.A.; Messiha, N. N. *J Appl Polym Sci*, **37**: 2051 (1989).
21. Shaaban, A. F.; Khalil, A. A.; Messiha, N. N. *Acta Polym*, **40**: 445 (1989).
22. Mahmoud, A. A.; Shaaban, A. F.; Khalil, A. A.; Messiha, N. N. Die Angew Makromol Chem, **198**: 31 (1992).
23. Khalil, A. A.; Moustafa, H. Y.; Arief, M. M. H. Eur Polym J 1996, 32, 647.
24. Khalil, A. A. *J Appl Polym Sci*, **99**: 2258 (2006).
25. Jayakumar, R; Balaji, R.; Nanjundan, *S. Eur Polym J*, **36**: 1659 (2000).
26. Lefiert, C.; Li. H.; Chidburee, S.; Hampson, S.; Workman, S.; Digel, D.; Epton, H.A.S.; Harbour, A. *J. Appl. Bacteriol.*, **78**: 97 (1995).
27. Fineman, M.; Ross, S. D. *J. Polym. Sci.*, **5**: 258 (1950).
28. Kelen, T.; Tudos, F. *J. Macromol. Sci. Chem.*, **A9** (1975).
29. Alfrey, T. Jr.; Price, C. J; *J. Polym. Sci.*, **2**: 101 (1947).
30. Young, L. J. Polymer Handbook 2ⁿᵈ ed. J. Brandrup and E. H. Immergut, Eds., New York, Wiley interscience pp.II 105-II.404 (1975).