Polymer Bulletin 47, 261–268 (2001)

Polymer Bulletin

Synthesis of a triacrylate crosslinking agent and its use in the preparation of macroporous polymers

Cesar G. Gomez, Miriam C. Strumia (✉)

Dpto. de Química Orgánica, Facultad de Ciencias Químicas, Universidad Nacional de Córdoba, Cdad. Universitaria, (5000) Córdoba, Argentina
e-mail: mcs@dqo.fcq.unc.edu.ar, Fax: 54-0351-4333030

Received: 17 April 2001 /Revised version: 4 September 2001 /Accepted: 5 September 2001

Summary

A triacrylate crosslinking agent, 2, 2′, 2″ - nitrilotriethyl triacrylate (NTETA), was synthesized through an original procedure from triethanolamine by a reaction with acryloyl chloride. Hydrophilic polymer supports were prepared by suspension copolymerization of 2-hydroxyethyl methacrylate (HEMA) with NTETA in an aqueous medium in the presence of cyclohexane (Cyc) as inert diluent. A new macroporous polymer, at a polymerization temperature of 85°C, was obtained. Porous properties of this copolymer were studied by swelling, mercury porosimetry and scanning electronic microscopy (SEM).

Introduction

Acrylates and methacrylates are two of the leading families of chain-growth monomers in use today [1-3], whose new applications rely on the possibility to meet increasingly complex combinations of chemical and physical properties.
The most efficient and controllable method, however, involves synthesis of multifunctional monomers that incorporates two or more different moieties or atoms into a single easily prepared molecule and repeat unit. These derivatives, in both homopolymers and copolymers, deal with potential applications of these materials in several fields, mainly in the property modification of commercial polymers and in biomedical applications [1-4], since relatively small amounts of highly functional materials may have a huge impact.
On the other hand, the study of porous crosslinking polymers with well defined porous structure, certain polarity and hydrophilic capacity has been of great interest [2,5-10]. These network types have been used as matrices of ion exchangers, chromatographic packing materials, polymer supports for catalysts and controlled drug release [1-4]. Specifically, the preparation of supports derived from HEMA monomer is a subject of great interest for biomedical and pharmaceutical applications [11]. Derivates have the major advantages of good biocompatibility and moderate degree of swelling in water, and are biologically inertia.
Recently, we have studied the influence of synthesis conditions by suspension polymerization on porous morphology of the polymeric networks [14]. The synthesis conditions studied included porogen type, radical initiator percentage, polymerization

temperature and monomers type. The final products were characterized and interesting conclusions were found. Through the H parameter obtained from swelling studies when ethylene glycol dimethacrylate (EGDMA) and HEMA were copolymerized by suspension polymerization, the best conditions to obtain a macroporous network with optimal yields and porous properties were reached. The sorption-expansion ratio (H) reflects the balance between swelling liquid sorbed and polymer network expansion.

In this work, we consider the combination of the two principal aims, synthesis and characterization of a trivinylic crosslinking agent, 2, 2′, 2″ - nitrilotriethyl triacrylate (NTETA) with a nitrogen atom as the central core, and its use in the preparation of macroporous network by suspension polymerization with HEMA as monovinylic monomer. This matrix was obtained under the same polymerization conditions previously studied and reported [14], when EGDMA was used as the crosslinking agent.

Experimental

Reagents and methods

The following chemicals were purchased and used: benzoic acid (BA), CICARELLI; acrylic acid (AAc), BASF; 2-hydroxyethyl methacrylate (HEMA), FLUKA; hydroquinone, AGFA; benzoyl peroxide (BPO), RIEDEL DE HAEN; Poly(vinylpyrrolidone) (PVP), (Kollidone 90); triethanolamine (TEA), ANHEDRA; thionyl chloride, RIEDEL DE HAEN; cyclohexane (Cyc), ANHEDRA; hexane, DORWIL; ethyl ether, SINTORGAN; chloroform, CICARELLI; Silica gel 60 (0.063-0.200 mm), MERCK.

The purified final product (NTETA) was characterized by ^{1}H-NMR and ^{13}C-NMR on a Bruker AC-200 Spectrometer. The IR spectra (cm^{-1}) were recorded on a Nicolet 5-SXC spectrometer.

The copolymer was synthesized using a 04644 - Series Digital Hot Plate/Stirrer (COLE/PARMER). The mercury porosimetry characterization was made with an AutoPore III Micromeritics 9410. The thermal study was evaluated by thermal gravimetric analysis (TGA) and differential scanning calorimetry (DSC), on a Universal V2.5H TA instrument. A rate of 10 °C / min under nitrogen atmosphere was used, starting from room temperature. Scanning electron microscopy (SEM) was performed on a Philips SEM 501B instrument.

Swelling studies were carried out in distilled water (pH: 6.5) and cyclohexane, respectively. Copolymer samples (100-120 mg) were left in contact with the swelling liquid in a special funnel (with a very small hole in a closed chamber) for 24 h followed by a 24 h drainage in the same closed chamber. When cyclohexane was used, the drainage time was 1 h. Then the wet samples were weighed in an analytical scale and the weights were measured at different evaporation times (each 15 s for 7-8 min after the sample was removed from the chamber). The data were processed using a plot of weight of wet sample (g) versus evaporation time (s), taking the weight of the sample in swollen state (W_{sw}) at time zero, which is achieved by extrapolation [14]. Subsequently, the samples were dried in a oven at 70 °C for 48 h and weighed to obtain the weight of the dry sample (W_{dry}). The equilibrium volume swelling ratio, q_v, (eq 2) was calculated by the ratio of the volume of samples in swelling equilibrium state (V_{sw}) and the volume of samples in dry state (V_{dry}). It was performed using

graduated tubes after the samples have been soaked 24 h in an excess of distilled water. The assays were realized for four time and the results were those with an error less than 5 %.
Then, the equilibrium weight swelling ratio (q_w), the equilibrium volume swelling ratio (q_v) and H parameter were determined.
The liquid regain (LR), was calculated as in equation (4), where d_1 was the liquid density, taken as 1.00 and 0.77 g / mL for the water and Cyc, respectively.

$$q_w = W_{sw} / W_{dry} \quad (1)$$
$$q_v = V_{sw} / V_{dry} \quad (2)$$
$$H = q_w / q_v \quad (3)$$
$$LR = (qw-1) / d_1 \quad (4)$$

Synthesis of crosslinking agent (NTETA):

NTETA was obtained using a new and original process of synthesis optimized in our lab. Benzoic acid and thionyl chloride were used as reagents at a molar ratio of 4:1 respectively and boiled for 15 minutes. The benzoyl chloride was obtained by simple distillation [17]. The benzoyl chloride was reacted with acrylic acid in molar ratio 2:1 forming acryloyl chloride, which was purified by fractional distillation [18]. The acryloyl chloride was slowly dropped from a dropping funnel on the triethanolamine in a flask with ice bath in a equivalents ratio 1.2:1, respectively. Then, the reaction was stirred at 0 °C for 1.5 h, 1 h at room temperature and finally at 45 °C for 6 h. The crude product (NTETA) was extracted from 0. 1 M Na_2CO_3 aqueous solution with chloroform, which was purified by chromatographic column (silica gel), using hexane and ethyl ether as the solvent system. The yield was 25 % of purified product, which was calculated through the percentage of NTETA obtained vs. total moles of TEA used.

Polymerization Reactions:

Copolymerization reactions were performed using a mol ratio of (3.0:1.0:9.3:2.5 10^2) of HEMA (0.49 mL), crosslinking agent (NTETA, 0.4028 g), inert diluent (Cyc, 1.38 mL) and water (6.13) mL respectively. In all cases the BPO was used as the free radical initiator, at a concentration of 2.44 mol% (vinylic monomers + BPO). Poly(vinylpyrrolidone) (0.0618 g) was used as the stabilizer of the suspension in a proportion of 10 mg/mL with respect to total mixture. In 40 mL flask, the reactions were stirred at 450 rpm for 2 h with a magnetic stir bar, 2 cm long and 0.5 cm wide. The temperatures assayed were 70 °C and 85 °C, respectively.
Copolymers were exhaustively washed with distilled water and ethanol. Later, they were dried in an oven at 70 °C to constant weight. The yield of each reaction was calculated through the percentage of dry matrix obtained vs. total grams of vinylic monomers used.

Results and discussion

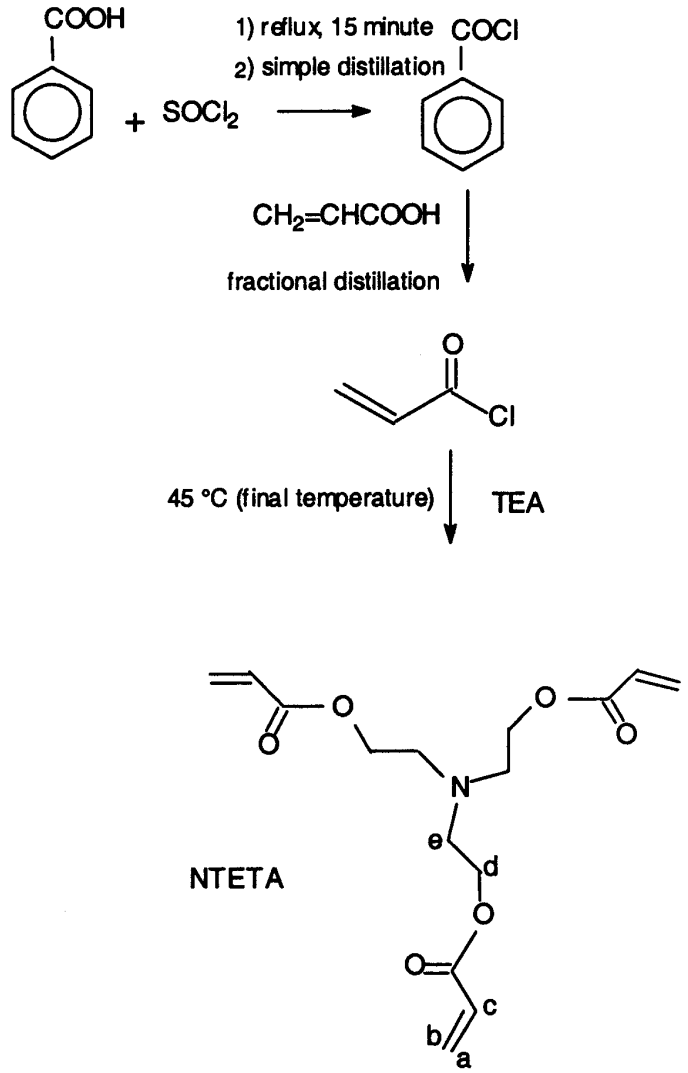
Synthesis of NTETA:

The general route for the synthesis of NTETA is shown in Scheme 1. The highest

yield (25 %), was obtained with 45 °C as the final temperature.
According to the molecular structures of the final product and reagent used, the high reactivity of the vinylic groups plays an important role in the synthetic route chosen. An adequate reaction temperature to avoid polymerization is necessary; thus its selection as a synthesis variable is an important factor which must be sufficiently low to inhibit the double bond reaction, but high enough to allow esterification to take place, for which an incremental temperature range (0 – 45°C) was selected.

Characterization of NTETA:

NTETA was characterized by FTIR, ^{1}H-NMR and ^{13}C-NMR, respectively [15, 16].
FT-IR: (KBr) stretching vibrations were found, corresponding to 2930 and 2860 cm^{-1} (C-H, CH_2) 1725 cm^{-1} (C=O, RCOOR') and 1630 cm^{-1} (C=C, CH_2=CH), respectively.
^{1} H-NMR: ($CDCl_3$, 200MHz) δ: 6.37 ppm (dd; J_{gem}: 1.46 Hz y J_{trans}: 17.18 Hz; 3 H, H^b CH=CH); δ: 6.09 ppm (dd; J_{cis}: 10.23 Hz y J_{trans}: 17.18 Hz; 3 H, $H_2C=CH^c$); δ: 5.81 ppm (dd; J_{gem}: 1.46 Hz y J_{cis}: 10.23 Hz; 3 H, H^a CH=CH); δ: 4.20 ppm (t; J: 5.85 Hz; 6 H, -O-CH_2^d); δ: 2.90 ppm (t; J: 5.85 Hz; 6 H, N-CH_2^e).



Scheme 1. Synthetic pathway of NTETA

[13] C-NMR: ($CDCl_3$, 50 MHz) δ: 165.84 ppm (-COO-); δ: 130.61 ppm (H_2C=); δ: 128.24 ppm (=CH-); δ: 62.58 ppm (O-CH_2-); δ:53.14 ppm (N-CH_2-).

Synthesis of copolymers:

An important effect of the reaction temperature in the synthesis of poly(NTETA-co-HEMA) was found. At 70 °C the insoluble product yield was 7 %, while at 85 °C it was 82 %. This can attributed to the different polymerization kinetics for each polymerization temperature.

Characterization of the copolymer obtained at 85°C:

The copolymerization reaction was assayed at 85 °C by the suspension polymerization technique, in the presence of Cyc as porogen agent. White particles with a distribution in the wide mm-range were obtained.

Swelling: it is known that swelling is ruled by two separate processes [2,8]: the liquid filling of pores determined by the volume of diluent separated from the network phase during polymerization and solvation of network chains determined by the volume of diluent remaining in the network structure during polymerization. Solvation depends on the crosslinking density and on the interaction between swelling liquid molecules and network chains.

According to the results obtained by Okay et al.[7], it is known that q_v is closely related with the stretching of the network as a function of the crosslinking density and on the interaction between swelling liquid molecules and network chains. Moreover, q_w of highly crosslinked networks depends mainly on the matrix porosity [9].

The H parameter was obtained using both swelling ratios (q_w and q_v), which reflects the balance between swelling liquid sorbed and polymer network expansion of copolymers. A high H value is indicative of a high retention of liquid with a low stretching degree, which is the ideal condition for macroporous networks with a rigid network [14]. Therefore, this parameter is closely related to the matrix porosity. The LR indicates the swelling liquid volume regain per gram of dry polymer.

As can be observed in Table 1, high values of q_w, LR and H exist for the product poly(NTETA-co-HEMA) obtained at 85 °C. This was attributed to the occurrence of macroporous structure in the polymeric network. In addition, different values of q_w, LR and H for each swelling liquid were found. This finding reflects the different affinities or each liquid by the copolymer.

The q_v value in water was higher than that found in Cyc, which is related to a major network expansion in water, pointing out the difference of the swelling liquid solvation power on the network chains. This behavior showed the hydrophilic characteristic in this copolymer, which would be due mainly to hydrogen bonds formed between water and HEMA hydroxyl groups. Low q_v values in both swelling liquids, indicate that network has a high crosslinking density.

IR spectroscopy: the IR spectrum of poly(NTETA-co-HEMA) was recorded on a KBr disk and showed the following characteristic signals: 3440 cm^{-1} (stretching vibrations of -OH group), 2960 cm^{-1} (stretching vibrations of C-H), 1730 cm^{-1} (stretching vibrations of C=O of ester group), 1320 - 1250 cm^{-1} and 1200 - 1150 cm^{-1} (stretching vibrations of C-O-C), 3100 - 2900 cm^{-1} and 1635 cm^{-1} (stretching vibrations of =C-H and C=C, respectively).

Table 1: Physical characteristics of the poly(NTETA-co-HEMA)[a] obtained at 85 °C

	Swelling	
	H_2O	Cyc
q_w	6.40	4.40
q_v	1.28	1.00
H	5.0	4.4
LR (mL / g)	5.4	4.4
	Mercury porosimetry intrusion	
	mesopore[b]	macropore[c]	total
V_p (mL / g)	0.16	2.97	3.13
S_s (m^2 / g)	66.4	9.5	75.9

a) Apparent density of the copolymer (d_0: 0.26 g / mL)
b) Pores with diameter > 2 nm ≤ 50 nm (IUPAC)
c) Pores with diameter > 50 nm (IUPAC)

Scanning Electronic Microscopy: the texture of the copolymer beads investigated by SEM (x 5000) is shown in Figure 1. The sample shows a very rough heterogeneous surface, which consists of agglomerates of nuclei and microspheres that look like cauliflower with large pores between the agglomerates.

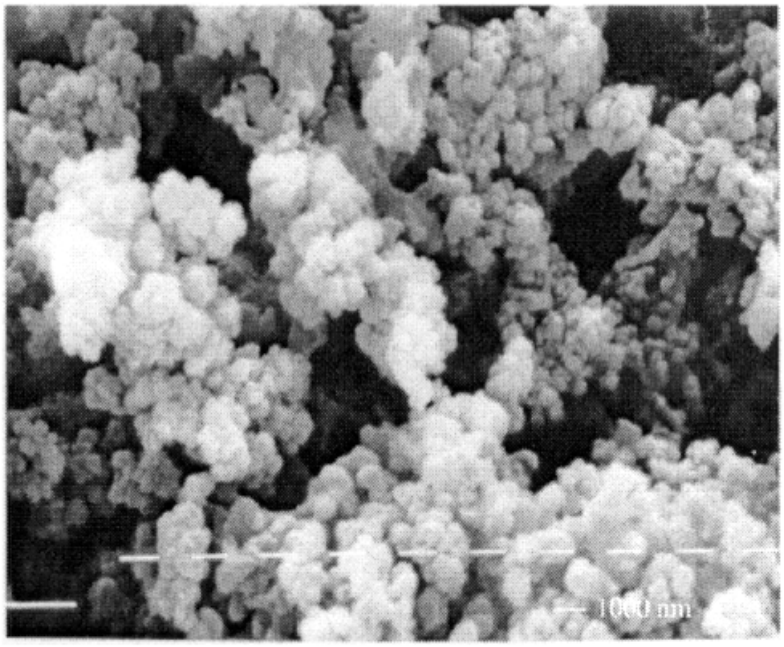


Figure 1. SEM of the poly(NTETA-co-HEMA) obtained at 85 °C. (— 1000 nm)

Mercury porosimetry intrusion: Table 1 shows specific pore volume, specific surface area and apparent density of the sample, which were measured in the dry state. The value of the total porosity (%P: 81.6) was defined as %P = Vp d_0 x 100 [7].
As shown in Figure 2, the presence of an important macropores distribution and noticeable specific surface area in the copolymer was corroborated. So, using NTETA as crosslinking agent with those reaction conditions, a macroporous polymer was obtained. This reveals that a phase separation was reached in the polymerization system.

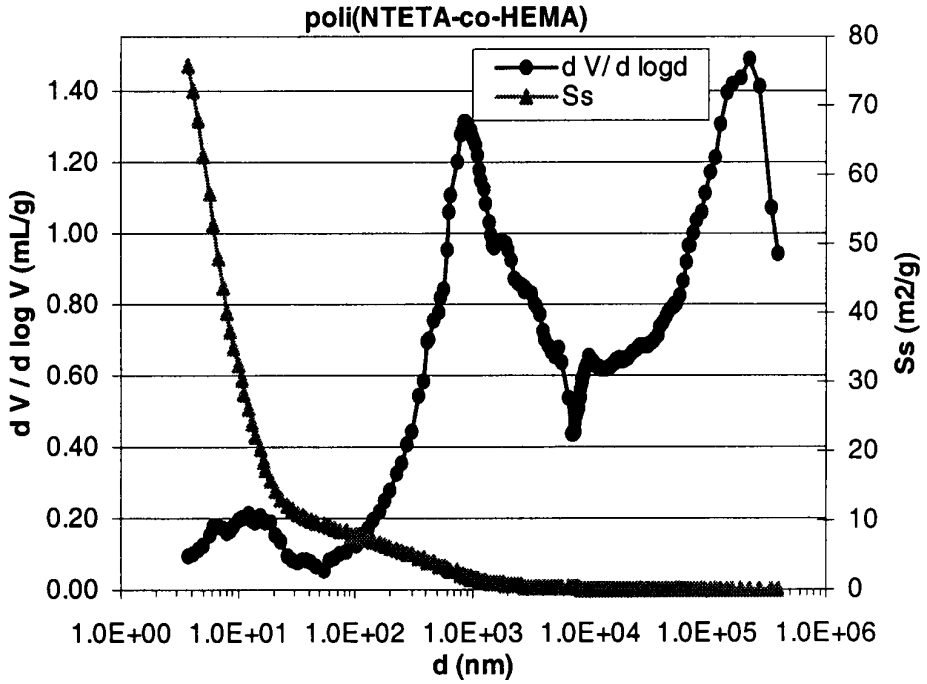


Figure 2. Pores distribution and specific surface area of poly(NTETA-co-HEMA)

Thermal analysis: thermal stability of poly(NTETA-co-HEMA) was measured by TGA and DSC. This copolymer begins degrading above 224 °C, with a weight loss of 50 % at 374 °C and 93 % at 496 °C, involving in all cases rupture of the chemical bonds.

Conclusion

A triacrylate crosslinking agent (NTETA) was synthesized by a reaction we optimized and obtained by a rapid process with a 25 % yield. From accessible commercial reagents it was obtained, purified, characterized and polymerized with HEMA to obtain new hydrophilic copolymers. These copolymers were synthesized by suspension polymerization, using Cyc as inert diluent and BPO as the free radical initiator.

The presence of macroporous structure in the polymeric network at 85 °C by swelling, mercury porosimetry and SEM was ratified. Thus NTETA is an excellent monomer for use in radical reactions by suspension polymerization, and a phase separation is reached in this polymerization system.

Acknowledgements.

The authors thank CONICOR, SECYT, CONICET and CYTED for their financial assistance. C. Gomez also acknowledges receipt of a fellowship from CONICOR.

References

1. D. Horák, J. Labsky' (1997) React & Funct Polym 32:277
2. D. Horák, F. Lednicky'and M. Bleha (1996) Polymer 37 (No. 19):4243
3. C. Huang, Y. Sun, W. Huang (1997) J Polym Sci A: Polym Chem 35:1873
4. A. Tuncel and E. Piskin (1996) J Appl Polym Sci 62:789
5. S. Jovanovic', A. Nastasivic', N. Jovanovic' and K. Jeremic' (1993) J Serb Chem Soc 58(5):343
6. C. Vlad, I. Poinescu and M. Barbu (1994) Eur Polym J 30 (No 8):863
7. O. Okay, E. Soner, A. Güngör and T. Balkas (1985) J Appl Polym Sci 30:2065
8. O. Okay (1986) J Appl Polym Sci 32:5533
9. I. Küçü, A. Kuyulu, O. Okay (1995) Polym Bull 35:511
10. C. Luz, F. Coutinho (2000) Eur Polym J 36:547
11. B. D. Ratner and A. S. Hoffman (1976) Hydrogels for Medical and Related Applications. Chap 1; ACS Symposium Series 31; Ed. Joseph D. Andrade, Washington, DC
12. M. Iza, S. Woerly, C. Danumah, S. Kaliaguine, M. Bousmina (2000) Polymer 41:5885
13. A. Nyhus, S. Hagen, A. Berge (2000) J Appl Polym Sci 76:152
14. C. Gomez, C. Alvarez, M. Strumia, R. Rivas, P. Reyes (2001) J Appl Polym Sci 79 (5):920
15. R. Conley (1972) Infrared Spectroscopy. Ed. Allyn Bacon, Inc.
16. D. Pasto, C. Johnson (1981) Determinación de Estructuras Orgánicas. Ed. Reverté S.A.
17. G. Stempel, R. Cross and R. Mariella (1950) J Am Chem Soc 72 (No 5-8): 2299
18. H. Lieb, W. Shöniger (1955) Preparaciones Orgánicas en Microescala. Ed. Aguilar S.A., Madrid