

# Reaction of Uric Acid with Excess of Propylene Carbonate

Jacek Lubczak

Department of Organic Chemistry, Rzeszów University of Technology, Al. Powstańców Warszawy 6, 35-959 Rzeszów, Poland

Received 10 December 2004; accepted 27 June 2005

DOI 10.1002/app.23507

Published online in Wiley InterScience (www.interscience.wiley.com).

**ABSTRACT:** New method of synthesis of polyetherols with purine ring by reaction of propylene carbonate with uric acid is presented. The influence of kind of catalyst, and molar ratio of substrates on structure, and physical properties of polyetherols; density, viscosity, surface tension, and refractive index were determined. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 101: 2482–2487, 2006

**Key words:** uric acid; propylene carbonate; ring-opening polymerization; heteroatom-containing polymers; structure-property relations

## INTRODUCTION

The interest of uric acid (UA) as potential substrate for synthesis of polyetherols, being the components to produce polyurethane foam of good thermal resistance is related to its polyfunctionality. UA possesses four functional groups and rigid purine ring, which renders the molecule thermally resistant. Degradation of purine ring occurs above 400°C.<sup>1</sup> Previously, it has been demonstrated that polyetherols suitable for thermally resistant polyurethanes could be obtained from oxiranes with *s*-triazine derivatives like isocyanuric acid<sup>2,3</sup> or melamine,<sup>4–6</sup> which decompose at 360 and 350°C, respectively.<sup>7</sup> The insolubility of UA in oxiranes precludes the straightforward reaction between UA with oxiranes. Moreover, because of low solubility of UA in DMSO (only 0.98 g in 23°C<sup>8</sup>) and also in water (0.5 g in 99°C<sup>9</sup>), the efficient, solvent assisted synthesis is impossible. The problem was solved by preliminary conversion of UA into its hydroxymethyl derivatives via reaction of UA with HCHO in formalin resulting in the formation of *N*-hydroxymethyl derivatives, which are far better soluble.<sup>10</sup> Those hydroxymethyl derivatives obtained from the mixtures at UA: CH<sub>2</sub>O 1:>6 molar ratio are resin semisolids after removal of water. They are miscible with oxiranes and react with them at elevated temperatures to give polyetherols according to the scheme 1 below.<sup>11,12</sup>

where  $x + y + z = 6$

$R = \text{—H, —CH}_3$ ;  $R' = \text{oxyalkylene group}$

The polyetherols obtained in that protocol were the basis for obtaining thermally resistant polyurethane foams.<sup>13</sup> Two-step protocol was the disadvantage of the synthesis; in the first step, the hydroxymethyl derivatives were obtained, which were subjected to further reaction with excess of oxiranes. Also, the necessity of vacuum removal of water, the use of high pressure reactors due to low-boiling point of oxiranes (ethylene oxide (EO), bp 24°C; propylene oxide (PO) bp 36°C), toxicity, and explosivity of substrates were the reason to search for other methods of synthesis.

Recently, we have demonstrated that using alkylene carbonates, instead of oxiranes, resulted in the formation of analogous products in reactions shown in scheme 2 below.<sup>14</sup>

The side product here is carbon dioxide; therefore, the polyetherols obtained by this method can be considered as adducts of UA to oxiranes. Alkylene carbonates are nontoxic and nonflammable, and thus are better candidates for environmentally friendly technologies. They also have high-boiling points, allowing thus to avoid high-pressure reactions.

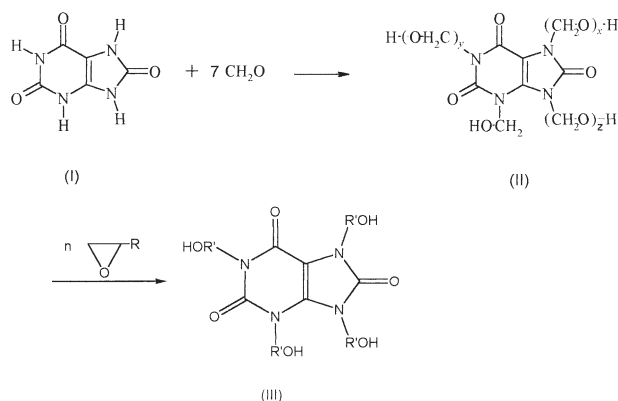
Here, we present a new method of synthesis of polyetherols with purine ring in straightforward reaction between UA and propylene carbonate (PC).

## EXPERIMENTAL

### Reactions of UA with PC

To the 250-cm<sup>3</sup> three-necked flask equipped with mechanical stirrer, thermometer, and reflux condenser, 16.8 g (0.1 mol) of UA (p., Avocado, Germany), 124.8 g (1.2 mol) of PC (p., Fluka, Switzerland) (see a) and 1 g of 55% aqueous solution of tetrabutylammonium hydroxide (TBAH pure, Fluka, Switzerland) catalyst

Correspondence to: J. Lubczak (jml@prz.rzeszow.pl).



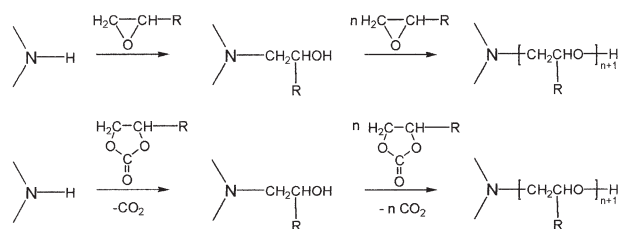
Scheme 1

were added (see b). The mixture was heated to and maintained at 185°C until the disappearance of PC. The reaction was stopped based on PC determination and mass balance (Table I).

- a. Starting UA : PC ratio was 1 : 12; polyetherols were also obtained at UA : PC = 1 : 8, 1 : 14, 1 : 16, 1 : 18, and 1 : 23 (cf. Table I).
- b. KOH was added after dissolving UA. Some reactions were performed with TBAH catalyst (see Table I, synthesis 1).

### Analytical methods

The course of reaction between UA and PC was followed by measuring the content of unreacted PC of reaction mixture by titrating a sample (dissolved in 0.3M barium hydroxide solution) with hydrochloric acid.<sup>15</sup> At the end of synthesis, the mass balance was determined with accuracy of 0.1 g. Hydroxyl numbers were determined by titration with a standard potassium hydroxide solution and by applying Glinka and Majewska method.<sup>16</sup> <sup>1</sup>H NMR spectra of PC and polyetherols were recorded on a spectrometer BS586A, 80 MHz, TESLA, Czechoslovakia (in *d*<sub>6</sub>-DMSO) with HMDS as internal standard. IR spectra of capillary films or in KBr pellets were recorded on a Specord 71 IR, Carl Zeiss, and PARAGON 1000 FTIR Perkin-Elmer spectrometers.



Scheme 2

Thermal analysis of the polyetherols was made using an F. Paulik, J. Paulik, and L. Erdey system derivatograph (MOM, Hungary) under the following condition of registration: sample mass 100 mg, temperature range 20–1000°C, nitrogen atmosphere, registration time 100 min, and amplifications DTA 1/10, DTG 1/15.

The GLC analysis of side products (i.e., propane-1,2-diol and products of its reaction with PC, formed during the reaction of UA with PC) was made on a Hewlett-Packard 5890 chromatograph (capillary column HP-FFAP; length: 10 m and diameter 0.53 mm; layer thickness: 0.1 μm; temperature: 20–220°C (20°C/min) and 5 min at 240°C; injector and detector: 220°C; carrier gas (He) rate: 18.3 cm<sup>3</sup>/min; and sample: 0.2 μL).

Series of reference substances were used: propane-1,2-diol (PD), 4-oxaheptane-2,6-diol (OHD), 2-methyl-3-oxahexane-1,5-diol (MOHD), and 5-methyl-4,7-dioxadecane-2,9-diol (MDODD). Details on calibration procedure was as before.<sup>17</sup>

### Properties of polyetherols—methods and procedures

Some physical properties of polyetherols were studied: viscosity was determined on Höppler viscosimeter (type BHZ, Prüfgeräte-Werk, Medingen, Germany), density was determined by piknometer method, surface tension was determined by the method of ring strap, and refraction coefficient was determined with Abbe refractometer.

### RESULTS AND DISCUSSION

Reactions of hydroxymethyl derivatives of UA with oxiranes; the oxymethylene fragment (—CH<sub>2</sub>O—) containing polyetherols are formed according to the scheme 3 below.<sup>11,12</sup>

Similar products are formed here, in reaction between UA and PC, but without oxymethylene insert. Synthesis was conducted at UA : PC 1 : 12 molar ratio, which was previously experienced in case of PO as suitable to give the resin product with all —NH groups reacted,<sup>12</sup> in the presence of TBAH (55% aqueous solution, added in 20.0 g/mol UA; see Table I), which was an effective catalyst for the reaction between isocyanuric acid and PC<sup>18</sup> at 185°C. At this temperature, the reaction progressed fast enough without considerable degradation of product(s), which were brownish, dense liquids.



Scheme 3

TABLE I  
Synthesis of Polyetherols from Uric Acid and Propylene Carbonate in Temperature 185°C

Entry	Initial PC molar excess per mole of IA	Reaction condition		Number of decomposed PC per UA	Oxyalkylene units per UA molecule	Hydroxyl number (mg KOH/g)	
		Time of dissolving of UA (h)	Reaction time (h)			Calcd.	Found
1	12	3.15	24	5.4	6.6	407.4	412.4
2	8	4.10	21	2.4	5.6	455.4	432.7
3	12	3.20	18	5.3	6.7	403.2	373.1
4	14	4.20	20	3.2	10.8	282.5	213.9
5	16	4.05	22	6.9	9.1	—	—
6	18	4.10	25	4.9	13.1	—	—
7	23	4.20	28	7.0	16.0	204.7	163.9

TBAH + KOH (20 + 2 g)/mol UA catalyst was used except entry 1, where exclusively TBAH was used (20 g/mole UA), and then KOH was added to reaction mixture after disappearance of solid uric acid.

Then, the procedure was slightly modified by the addition of KOH catalyst (2.0 g/mol UA). It was added after dissolving of UA with preliminary derivatization to avoid formation of insoluble potassium urate. With this protocol, reaction was faster (Table I, compare syntheses 1 and 3); therefore, further experiments were done with TBAH and KOH mixed catalysts. Series of syntheses were performed at UA : PC = 1 : 8, 1 : 14, 1 : 16, 1 : 18, and 1 : 23 (Table I, entries 2–7). It has been observed that higher the excess of PC used, the longer reaction time was needed, and products obtained were less dense and viscous (Table II). From the results in Table I, it can be noticed that part of PC decomposed at reaction conditions to give carbon dioxide and PO,<sup>19</sup> which left the reactor.

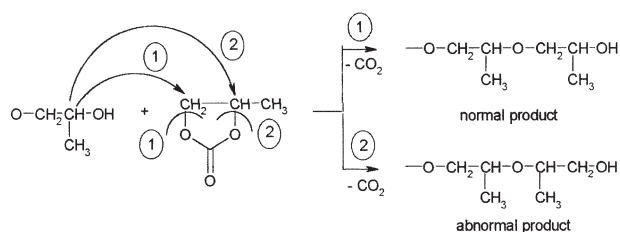
The calculation in Table I are correct provided there is no unreacted PC in the system, which has been checked based on <sup>1</sup>H NMR spectrum of postreaction mixture that showed no presence of characteristic pattern of resonances from PC, i.e., doublet from methylene protons at 1.3–1.4 ppm, triplet and unresolved multiplet in the region of 3.9–4.2 and 4.4–5.0 ppm, respectively, from —CH<sub>2</sub>— and —CH—. These resonances were used as diagnostic for monitoring the progress of reaction and were absent in final polyetherols (Fig. 1).

In the spectra of products, the resonances at 0.9–1.0 and 4.2–4.8 ppm regions were assigned to methyl and

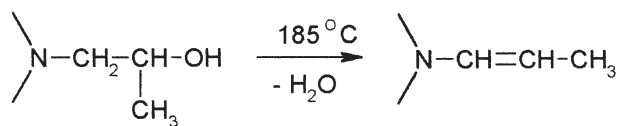
methine protons, respectively, while methylene group protons absorb in the region of 3.2–3.8 ppm. The integral intensity ratio of methyl to methylene and methine proton resonances was 1 : 1, which evidences the structure IV of final polyetherols. On the basis of spectral observation, one can suggest the path of ring opening of PC that can occur on two ways to give so-called normal and abnormal products<sup>11,12</sup> (see Scheme 4):

The diagnostic is chemical shift of methyl protons.<sup>12</sup> On the basis of percentage of the methyl proton resonances for normal and abnormal products, we have concluded that, for the reaction in acidic conditions (in the presence of imide protons from UA), there is about 30% of abnormal product formed in the UA : PC 1 : 8 system. On increasing the PC amount, the imide groups of UA gets blocked and reaction environment becomes basic (due to basic character of catalyst) and less abnormal product is formed (~20% at UA : PC 1 : 12). These observations corroborate well with the previous results with propylene oxide substrate.<sup>11,12</sup>

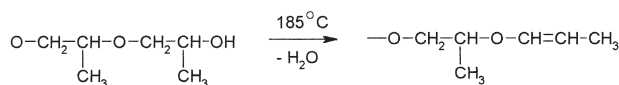
Moreover, the examination of the <sup>1</sup>H NMR spectra of products obtained with increasing excess of PC indicate the presence of resonances in the 4.8–4.2 and 4.9–5.3 ppm regions from protons attached to unsaturated carbon atoms. This evidences the reactions (5) and (6) that take place (see Schemes 5 and 6):



Scheme 4



Scheme 5



Scheme 6

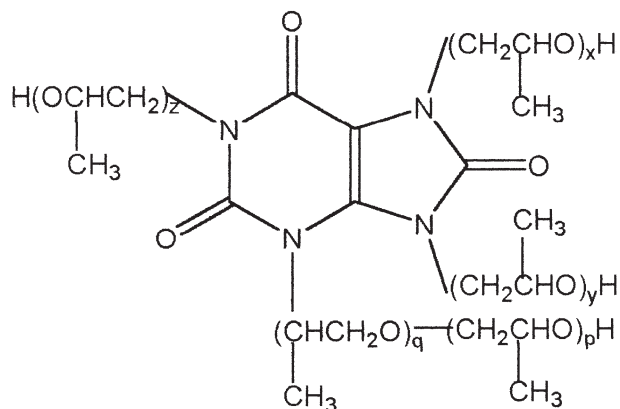
TABLE II  
Some Physical Properties of Polyetherols and Regression Equations Describing Their Dependence on Temperature, in the Range of 20–80°C

Run no.	Surface tension $\tau$ (N/m) $10^3$			Refraction index $n_{20}^D$ [-]			Viscosity $\eta$ (N s/m <sup>2</sup> ) $10^3$				Density $d$ (g/cm <sup>3</sup> )		
	$\tau = aT + b$			$n = aT + b$			$\eta = A + be^{-T/c}$				$d = aT + b$		
	$a$	$b$	$r$	$a 10^4$	$b$	$r$	$a$	$b$	$c$	$r$	$a 10^4$	$b$	$r$
1	-0.149	34.15	0.9989	-3.36	1.5020	0.9999	152.34	145513.3	8.63	0.9998	-8.03	1.1647	0.9985
3	-0.111	32.55	0.9996	-3.32	1.4949	0.9994	39.52	21974.8	10.7	0.9996	-7.86	1.1615	0.9983
4	-0.128	32.70	0.9972	-3.45	1.4957	0.9995	69.74	45822.0	9.32	0.9998	-7.26	1.1410	0.9998
5	-0.138	30.02	0.9942	-3.48	1.4908	0.9999	26.71	12659.2	10.47	0.9989	-7.56	1.1306	0.9943
6	-0.069	28.38	0.9986	-3.51	1.4860	0.9998	17.48	4651.64	11.66	0.9996	-7.41	1.1096	0.9998
7	-0.056	27.72	0.9989	-3.61	1.4792	0.9996	1.698	684.96	17.80	0.9994	-8.49	1.0988	0.9965

$r$ , correlation coefficient.

The presence of those products becomes noticeable at the system UA : PC 1 : 8, when prolonged heating of reaction mixture is necessary to complete the reaction.

On the basis of the above observations, the structure (IV) can be postulated:



where:  $x + y + z + p + q = n$   
 $n$  is the number of oxyalkylene units.

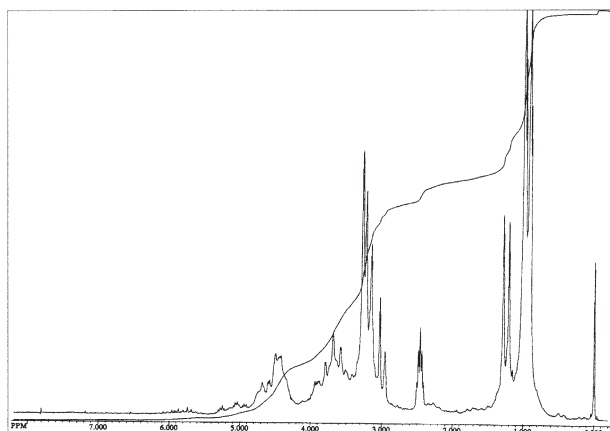


Figure 1 <sup>1</sup>H NMR spectrum of the product of reaction obtained from UA : PC = 1 : 16 substrate mixture.

The <sup>1</sup>H NMR spectral feature corroborate well with IR spectroscopic results. The IR spectrum of UA is consistent with trisketoform with characteristic band at 1676 cm<sup>-1</sup>, ring band at 1600 cm<sup>-1</sup> overlapped with amide band II.<sup>20</sup> Valence vibrations from imide and imine —NH are located at 2600–3100 cm<sup>-1</sup> range. Figure 2 shows the spectral changes occurring during the reaction of UA with PC. The presence of broad  $\nu$ (OH) band at 3400–3380 cm<sup>-1</sup> indicates the formation of associates with hydrogen bonds. In the 2800–2900 cm<sup>-1</sup> region, the methylene group band is growing upon progress of reaction, the higher intensity at larger excess of PC applied. The presence of  $\nu$ (C=O) at 1680 cm<sup>-1</sup> and  $\nu$ (C=C) at 1620 cm<sup>-1</sup> bands in products evidences that the purine ring is preserved in product(s). The presence of primary and secondary hydroxyl groups is confirmed in IR spectrum by the presence of  $\nu$ (C—O) bands at 1043–1052 cm<sup>-1</sup> and 1070–1088 cm<sup>-1</sup>, respectively, as well as deformation mode band at 1340 cm<sup>-1</sup>.

The products were analyzed by GC method to determine low-molecular weight side products (diols and products of its consecutive reactions) and unre-

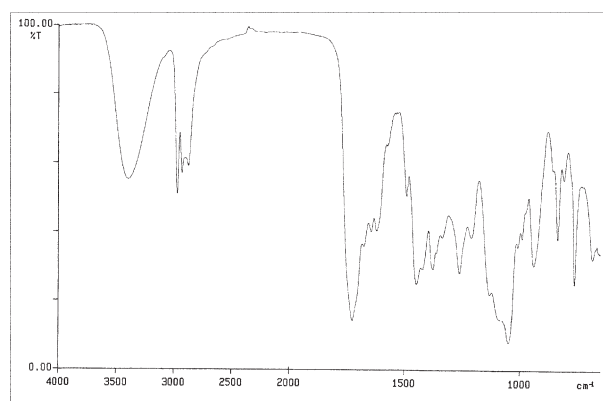


Figure 2 IR spectrum of the product of reaction obtained from UA : PC = 1 : 16 substrate mixture.

acted substrates in final products. Possible side reaction could be that between PC and trace water and water formed in dehydration step (reactions (4) and (5)). It has been found, that at low excess of PC, the percentage of propane-1,3-diol and its consecutive products is lower than 20% (Table III). Upon increase of number of PC moles applied, the percentage of propane-1,3-diol decreases in expense of amount of consecutive products, and finally at UA : PC ratio 1 : 18, it is only 2% of diol remaining. This is probably due to its disappearance in the reaction with PC. Amount of consecutive products decreases to 15%.

Thermal resistance of products was determined by DTA method. The 10% mass loss on DTG curve (Fig. 3) is observed at 170°C, which corresponds to evaporation of propane-1,2-diol. The effect is accompanied by two overlapping endothermic effects on DTA curve at 270 and 320°C. The first one is related to decomposition of diols present in postreaction mixture, while the second one was assigned to decomposition of purine ring. Thus, polyetherols obtained here have higher thermal resistance than those obtained from hydroxymethyl derivatives of UA and oxiranes, which decomposed beginning from 120°C.<sup>11</sup>

Some other physical properties were also studied (Table II). From the data in Tables I and II, one can conclude that upon increase of PC equivalents used in synthesis, the hydroxyl number, density, viscosity, and surface tension of the products decrease. Temperature dependence of density, viscosity, and surface tension of products also undergoes considerable changes. The obtained values of physical parameters indicate that obtained polyetherols can be successfully applied for the synthesis of foamed polyurethane materials. The latter will be the issue of separate report.

## CONCLUSIONS

Polyetherols that are obtained at the straightforward reaction between UA and PC in the presence of TBAH and KOH catalysts at 185°C contain purine ring incor-

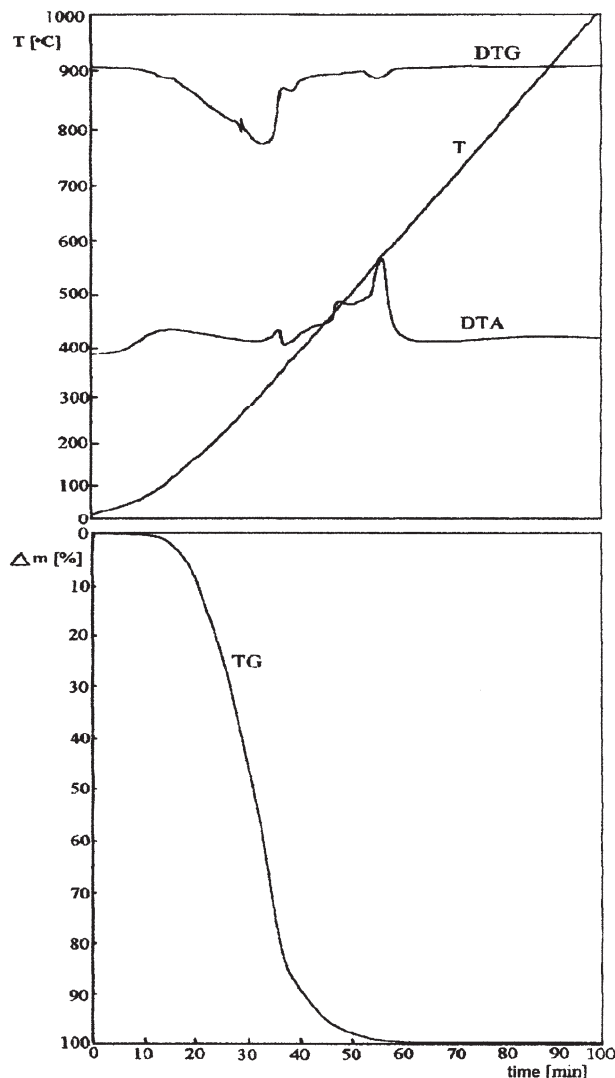


Figure 3 Thermal analysis of the product of reaction obtained from UA : PC = 1 : 16 substrate mixture.

TABLE III  
GC of By-Products Arising in the UA with PC Reactions

Run no.	Side products (wt %)					Polyetherol content (wt %)
	PD	OHD	MOHD	MDODD	Σ%	
1.	14.8	4.0	0.8	0.0	15.6	80.4
2.	17.0	2.2	0.0	0.0	19.2	80.8
5.	10.1	6.2	2.3	0.1	18.6	81.4
6.	2.2	8.4	3.4	0.5	14.5	85.5

Abbreviations used: PD, propane-1,2-diol; OHD, 4-oxaheptane-2,6-diol; MOHD, 2-methyl-3-oxaheksane-1,5-diol; MDODD, 5-methyl-4,7-dioxadecane-2,9-diol.

porated in the structure of product. This allows to replace previous two-step method of synthesis and use nonhazardous substrate, alkylene carbonate, instead of alkene oxides. The purine ring incorporated in the polyetherol structure renders them attractive substrates for production of thermally resistant high-molecular products.

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