

# Reactions of Adenine with Ethylene Oxide and Propylene Oxide

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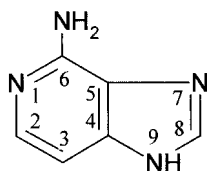
**ABSTRACT:** Reactions leading to thermostable polyetherols containing purine rings were studied. Products of reaction of adenine and an excess of the oxiranes were analyzed by proton nuclear magnetic resonance and infrared spectroscopies. The physical properties of some of the

products were determined. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 86: 489–497, 2002

**Key words:** monomers; oligomers; polyethers; thermal properties

## INTRODUCTION

Simple methods of manufacturing polyurethane foams of improved thermal stability are still sought. In addition to the methods involving *in situ* formation of isocyanate trimers,<sup>1–3</sup> one of the approaches is to prepare polyetherols containing groupings known for their thermal resistance, such as the same *s*-triazine rings that are formed in the trimerization.<sup>4–6</sup> A similar effect has been achieved by introducing into polyetherol structures another nitrogen-containing heterocyclic rings (e.g., purine rings).<sup>7</sup> This work deals with the reactions leading to such products; namely, with oxyethylation or oxypropylation of adenine (I) that contains a purine ring, providing an improved thermal resistance to products based on this compound.



(I)

## EXPERIMENTAL

### Syntheses

In a 250-cm<sup>3</sup> glass autoclave equipped with mechanical stirrer and heating jacket, 3.4 g (0.025 mol) of

adenine (pure, Avocado, Germany), 0.3 g of DABCO (1,4 diazabicyclo [2.2.2]octane, pure, Avocado, Germany), or 2.5 cm<sup>3</sup> of triethylamine (TEA, Fluka, Switzerland) as catalysts, 100 cm<sup>3</sup> of dimethylformamide (DMF; pure, Lab-Scan, Ireland) or dimethylsulfoxide (DMSO; pure Lab-Scan, Ireland) as solvents, and a predetermined amount of ethylene oxide (EO; pure, Fluka, Switzerland) or propylene oxide (PO; pure, Fluka, Switzerland) were placed. The molar ratio of adenine to oxirane was changed in the range from 1:1 to 1:17 (Table I). The mixture was heated while stirred to 95 °C and kept at this temperature until reaction was completed. The conversion was followed by determining the epoxy number of reacting mixture by titrating samples withdrawn with standard hydrochloric acid in dioxane.<sup>8</sup> The solvents were removed from the final mixtures by distilling them off under reduced pressure ( $p = 1.33 \cdot 10^3$  Pa, temperature = 48–75 °C).

### Spectral and elemental analyses

The final mixtures were freed from DMF or DMSO, and, depending on the form of samples, their proton nuclear magnetic resonance (<sup>1</sup>H NMR) or infrared (IR) spectra were recorded. A Fourier transform (FT) <sup>1</sup>H NMR 80 MHz, BS 586 A spectrometer (TESLA, Czechoslovakia) was used for d<sub>6</sub>-DMSO solutions at 25 ± 0.2 °C in the range 0–13 ppm, with hexamethyldisiloxane as an internal standard. A FT IR PARAGON 1000 spectrometer, Perkin-Elmer, UK, was used for capillary film or KBr tablets.

The elemental composition of products was determined on a CARLO ERBA EA 1108 instrument (CHN configuration), and molar masses were measured with

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TABLE I  
Results of Reaction of Adenine with EO or PO at 90–95 °C<sup>a</sup>

Oxirane	Adenine: oxirane molar ratio	Solvent	Catalyst	Unreacted groups [moles]				Reacted groups [moles]		Moles of oxirane reacted with	
				—N(9)H	—NH <sub>2</sub>	—NH—CH <sub>2</sub> —CHR—O—	Σ—NH	—N(9)H	Σ—NH	—NH	—OH
PO	1:1.0	DMSO	TEA	0.0	1.00	0.00	2.00	1.0	1.0	1.0	0.0
	1:1.2	DMSO	TEA	0.0	0.90	—	1.80	1.0	1.2	1.2	0.0
	1:1.6	DMSO	TEA	0.0	0.56	0.25	1.40	1.0	1.6	1.6	0.0
	1:2.3	DMSO	TEA	0.0	0.30	0.54	1.10	1.0	1.9	1.9	0.4
	1:2.9	DMF	TEA	0.0	0.17	0.50	0.80	1.0	2.2	2.2	0.7
	1:3.0	DMF	DABCO	0.0	0.12	0.33	0.58	1.0	2.4	2.4	0.6
	1:6.7	DMF	DABCO	0.0	0.00	0.00	0.00	1.0	3.0	3.0	3.7
	1:10.0	DMF	DABCO	0.0	0.00	0.00	0.00	1.0	3.0	3.0	7.0
EO	1:1.0	DMF	DABCO	0.0	1.00	0.00	2.00	1.0	1.0	1.0	0.0
	1:2.5	DMF	DABCO	0.0	0.20	0.10	0.50	1.0	2.5	2.5	0.0
	1:4.0	DMF	DABCO	0.0	0.15	0.60	0.90	1.0	2.1	2.1	1.9
	1:4.5	DMF	DABCO	0.0	0.10	0.00	0.20	1.0	2.8	2.8	1.7
	1:8.8	DMF	DABCO	0.0	0.00	0.00	0.00	1.0	3.0	3.0	5.8
	1:9.5	DMF	DABCO	0.0	0.00	0.00	0.00	1.0	3.0	3.0	6.5
	1:12.1	DMF	DABCO	0.0	0.00	0.00	0.00	1.0	3.0	3.0	9.1
	1:16.8	DMF	DABCO	0.0	0.00	0.00	0.00	1.0	3.0	3.0	13.8

<sup>a</sup>R = —H (EO); R = —CH<sub>3</sub> (PO).

a FISONs gas chromatography-mass spectrometry (GC-MS)-type mass spectrometer MD 800.

amplifications of 1/15 for differential thermal analysis (DTA) and 1/10 for differential thermal gravimetry (DTG), and a recording time of 100 min.

### Physical properties

For the resinous products, the refractive index, viscosity, and surface tension were determined. Their thermal properties were determined in nitrogen on a Paulik–Paulik system MOM derivatograph (Hungary) using 0.5-g samples, a temperature range 20–1000 °C,

### RESULTS AND DISCUSSION

The reactions of adenine with oxiranes were carried out in different solvents and in the presence of different catalysts. Initially, the reactions were carried out in

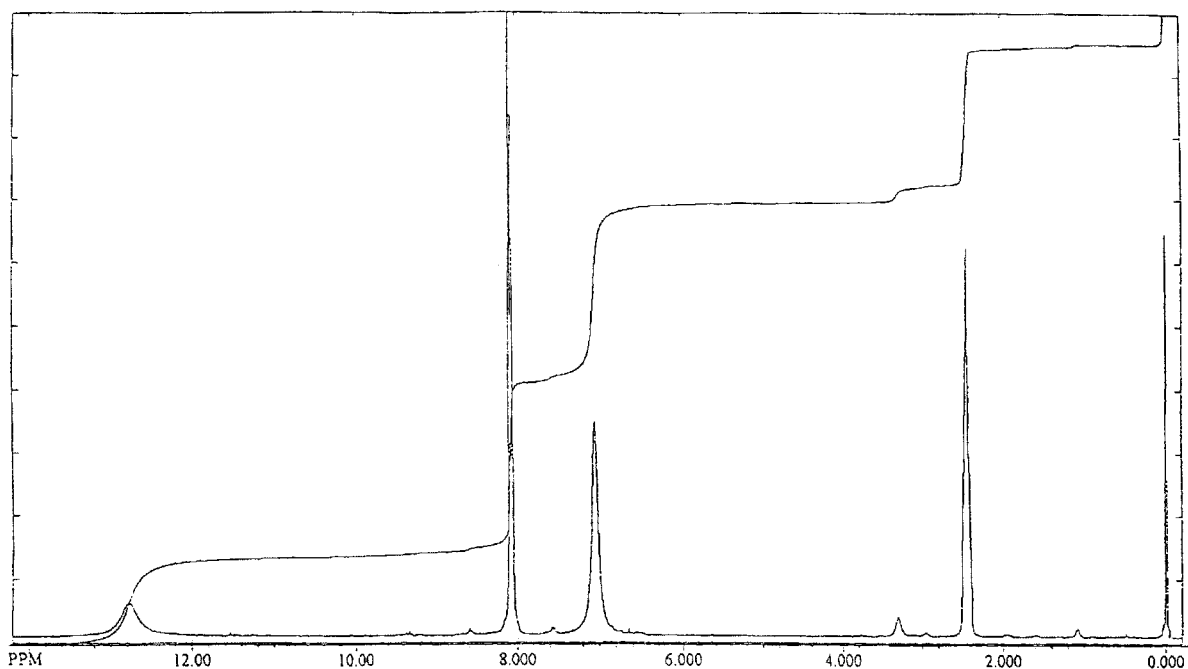


Figure 1 <sup>1</sup>H NMR spectrum of adenine.

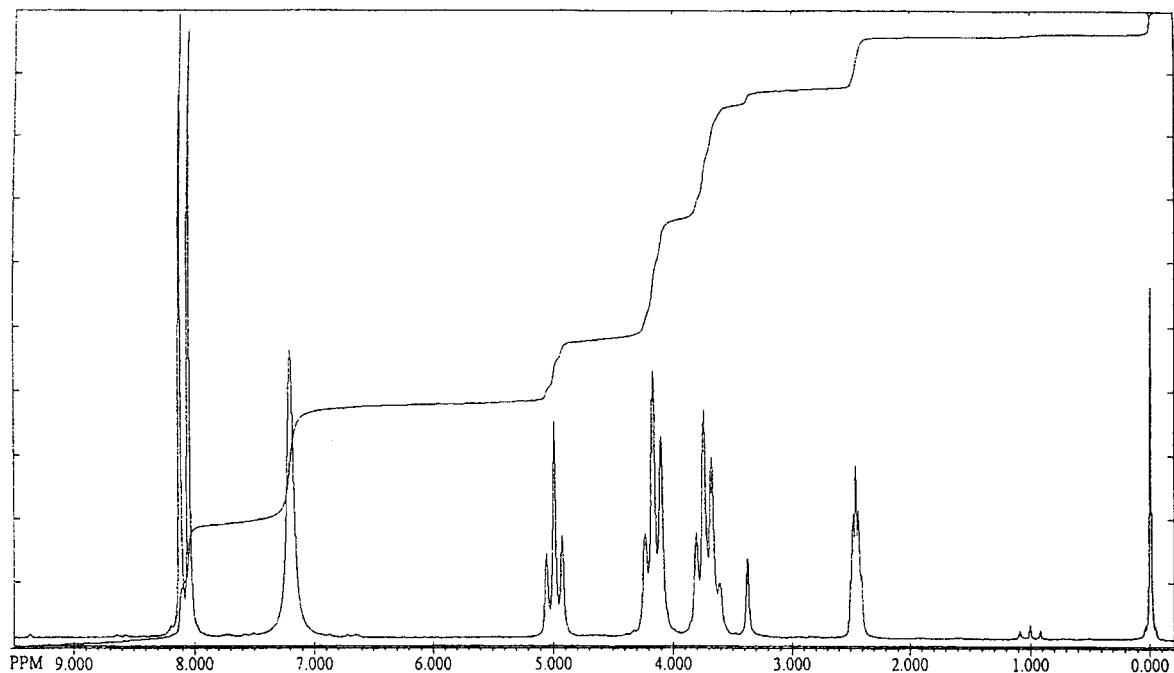


Figure 2  $^1\text{H}$  NMR spectrum of the product of the reaction of adenine with EO at the molar ratio 1:1.

DMSO (at 90–95 °C), the best solvent of adenine, and in the presence of a TEA catalyst, which is typical for oxyalkylation with oxiranes. PO reacted very slowly under these conditions (46 h). Furthermore, it was difficult to remove all the solvent that had a relatively high boiling point (189 °C) and that decomposed into products of unpleasant odor at room temperature

from the resulting samples of high viscosity or even semisolid.

Because of this difficulty, DMSO was replaced by somewhat more volatile DMF (boiling point, 153 °C; solubility, 0.3 g of adenine in 100 g of DMF at 50 °C). Even then, in the presence of TEA catalyst and at a large excess of oxirane, the conversion degree of PO

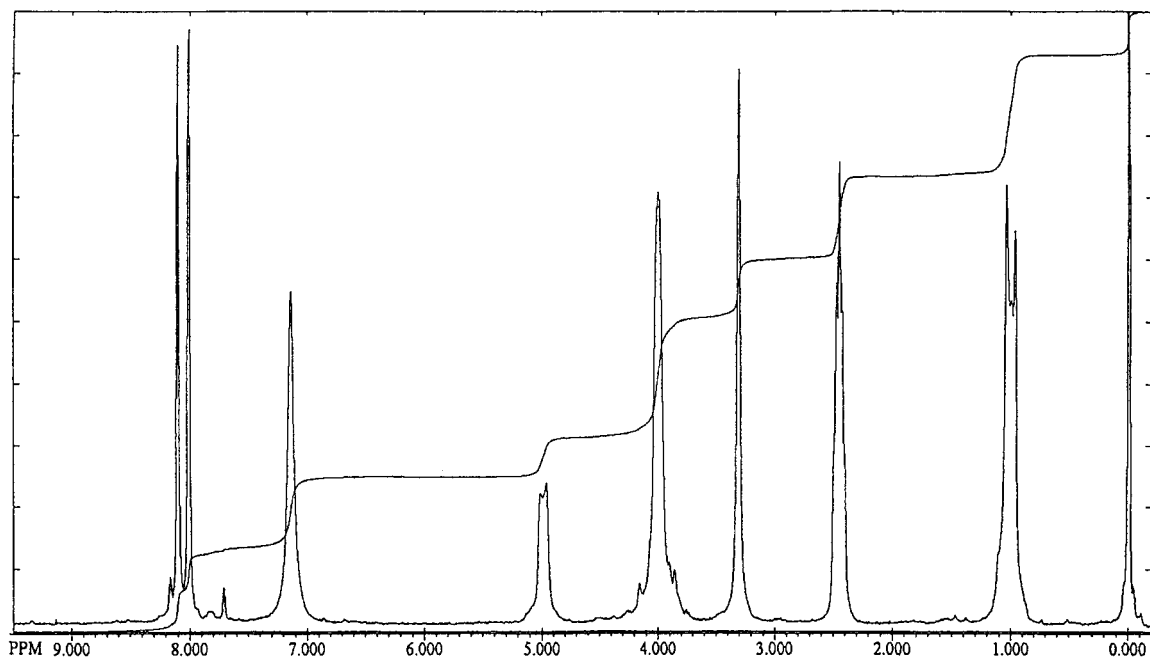


Figure 3  $^1\text{H}$  NMR spectrum of the product of the reaction of adenine with PO at the molar ratio 1:1.

TABLE II  
Calculated and Found Elemental Composition and Physical Data of Products  
of Addition of EO or PO (1 mol) to Adenine

Compound	Elemental composition			Molar mass [g/mol]	Melting point [°C]
	%C	%H	%N		
2-(Adenin-9-ylo)ethanol	46.93	5.06	39.07	179	— <sup>a</sup>
Product of addition of adenine to EO at molar ratio 1:1	47.83	5.00	38.38	179	245
2-(Adenin-9-ylo)-1-methyloethanol	49.75	5.74	36.24	193	— <sup>a</sup>
Product of addition of adenine to PO at molar ratio 1:1	49.97	5.99	35.14	193	188–190

<sup>a</sup>Not found.

was small, similar to that in DMSO solution. Evidently, a more effective catalyst was needed. Basing on experience from studies on melamine oxyalkylation,<sup>9</sup> DABCO was selected as a catalyst. This catalyst used in DMF solution proved to be more effective than TEA. With this catalyst, amino groups of adenine were all blocked even at the 6-fold molar excess of PO.

The course of reaction of adenine with oxiranes and the average composition of the products was followed by <sup>1</sup>H NMR analysis of the final reaction mixtures (after solvent had been removed) obtained at various molar ratios of reagents. Three types of protons are seen in <sup>1</sup>H NMR spectrum of adenine (Figure 1). The most acidic one, which is that at N(9) (nitrogen atom number 9 in the ring),<sup>10</sup> resonates first at 12.8 ppm. Then, a signal appears from protons at C(2) and C(8) at 8.1 ppm and, finally, a signal at 7.1 ppm from protons of amino groups. The ratios of areas under the peaks are consistent with the numbers of respective protons, namely 1:2:2, respectively. The signals at 12.8

and 7.1 ppm have been verified to belong to labile protons; the signal intensities decreased when heavy water was added.

Reaction of 1 mol of adenine with 1 mol of EO in DMF yielded a crystalline solid with a melting point of 244 °C and a molar mass of 179. Hence, the product was the 2-hydroxyethyl derivative of adenine. Its <sup>1</sup>H NMR spectrum (Figure 2) suggests that it is the proton at N(9) that is substituted by 2-hydroxyethyl group. The intensity of the signal at 5.0 ppm indicates that exactly one hydroxyethyl group has been introduced per molecule of adenine. It is interesting that the protons in the amino group of adenine at C(6) (7.1 ppm) are not substituted by hydroxyalkyl groups at all. Both the signals at 5.0 and 7.1 ppm disappear after heavy water is added to the samples. Similar conclusions also apply to the spectrum of the product of 1 mol of adenine with 1 mol of PO (Figure 3). Hence, the structure of products obtained in reactions carried out at stoichiometric ratio of reagents is

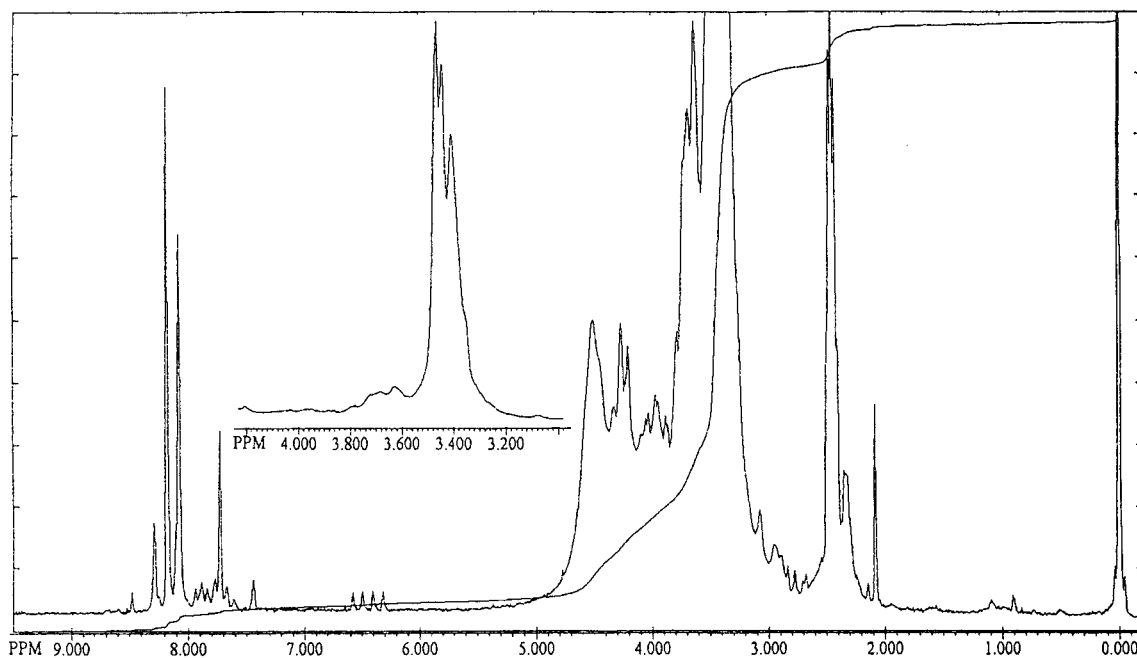


Figure 4 <sup>1</sup>H NMR spectrum of the product of the reaction of adenine with EO at the molar ratio 1:12.1.

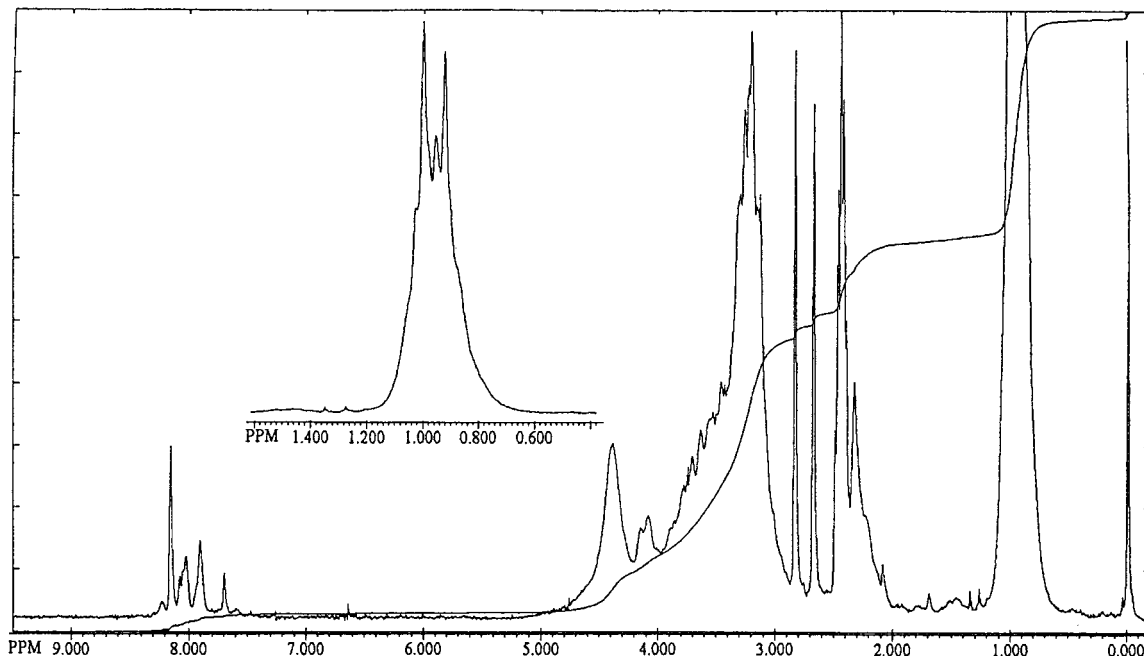
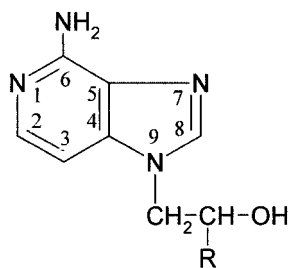


Figure 5  $^1\text{H}$  NMR spectrum of the product of the reaction of adenine with PO at the molar ratio 1:10.



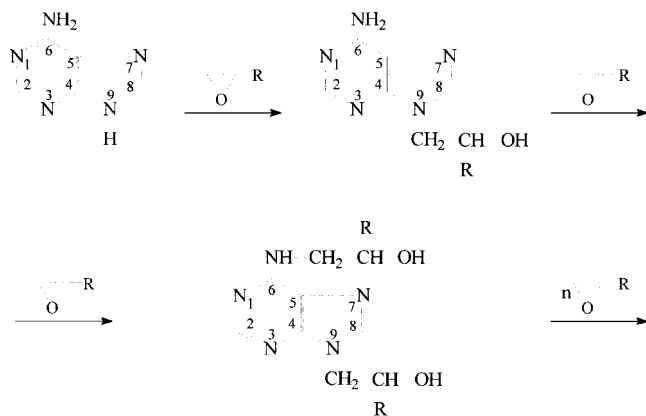
(II)

shown in structure II, where R =  $-\text{H}$  (IIa),  $-\text{CH}_3$  (IIb).

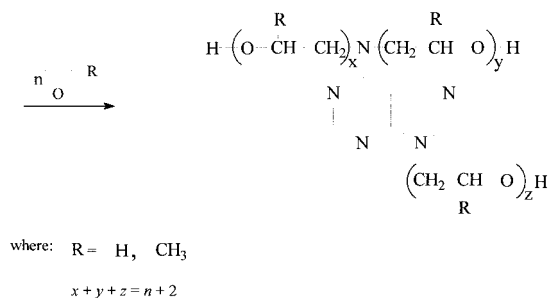
From the spectrum of (IIa) one can clearly determine the respective ratios of signals from protons in  $=\text{CH}$ ,  $-\text{NH}_2$ ,  $\text{N}-\text{CH}_2$ ,  $-\text{CH}_2\text{O}$ , and  $\text{OH}$  to be 2:2:2:2:1. In compound IIb, the ratios for protons in  $=\text{CH}$ ,

$\text{NH}_2$ ,  $\text{N}-\text{CH}_2$ ,  $-\text{CHO}$ ,  $\text{N}-\text{CH}_2$ ,  $\text{CH}_3$ ,  $\text{OH}$  is 2:2:1:2:3:1, exactly as in the aforementioned formula. The same conclusion follows from the results of elemental analysis (Table II). One should also point out that substitution of hydrogen at N(9) with 2-hydroxyalkyl group slightly shifts the signal of proton at  $=\text{C}(8)\text{H}$ .

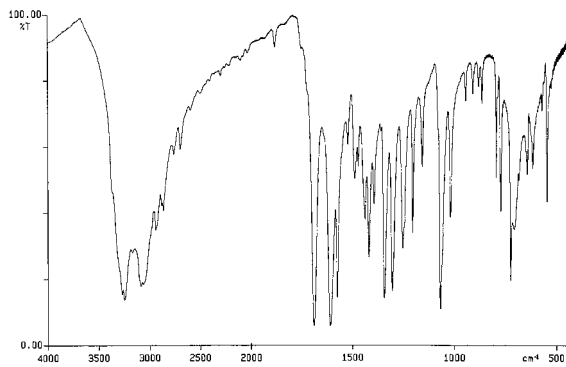
The protons of methylene group  $\text{N}(9)-\text{CH}_2-$  in the products of reaction of adenine with 1 mol of both EO and PO produce a signal at 4.15 ppm, whereas those at groups  $-\text{CH}_2\text{O}-$  and  $>\text{CH}-\text{O}-$  yield signals in the range 4.5–4.7 ppm. Spectra provide evidence of the more substituted products containing more oxyalkylene groups (Figures 4 and 5). The signals from groups  $-\text{CH}_2\text{O}-$  and  $>\text{CH}-\text{O}-$  become more intense, and signals from amino protons become weaker. Successive oxirane molecules gradually block the latter. Furthermore, in the range 4.5–4.7 ppm, the spectra become somewhat more complex because of the presence of signals from protons in methylene groups linked to the amino group of adenine. Detailed results of the analysis of  $^1\text{H}$  NMR spectra of the prod-



Scheme 1



Scheme 2



**Figure 6** IR spectrum of the product of the reaction of adenine with EO at the molar ratio 1:1.

ucts of reaction of adenine with EO or PO are presented in Table I. The signal at 7.9 ppm, due to protons at group =CH that does not react with oxirane, has been used as a reference. The numbers,  $n_{\text{group}}$ , of individual functional groups were calculated using the following equations

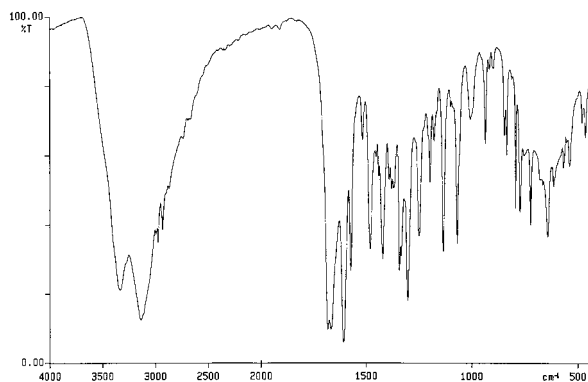
$$n_{\text{NH-R}} = n_{\text{N(9)-H}} = \frac{2S_{\text{N(9)-H}}}{S_{\text{=CH}}}$$

$$n_{\text{NH}_2} = \frac{S_{\text{NH}_2}}{S_{\text{=CH}}}$$

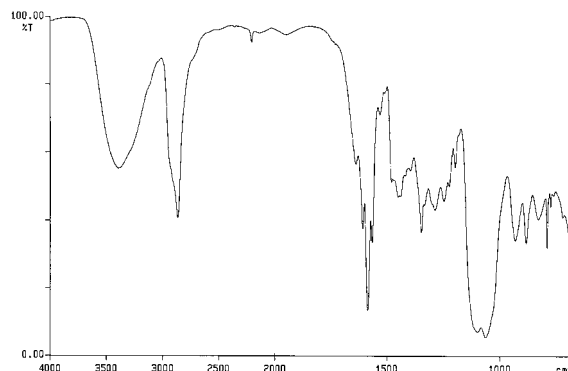
$$n_{\text{OH}} = \frac{2S_{\text{OH}}}{S_{\text{=CH}}}$$

where  $S_{\text{group}}$  denotes the area under the respective functional group in the products of reaction of adenine with oxiranes.

As follows from the data in Table I, the first mole of oxirane (EO or PO) reacts exclusively with N(9)—H groups. No other simultaneous reactions of oxirane occur with, for example, amino group of adenine or subsequent reactions of oxirane with hydroxyalkyl groups. The subsequent reactions start to be seen only



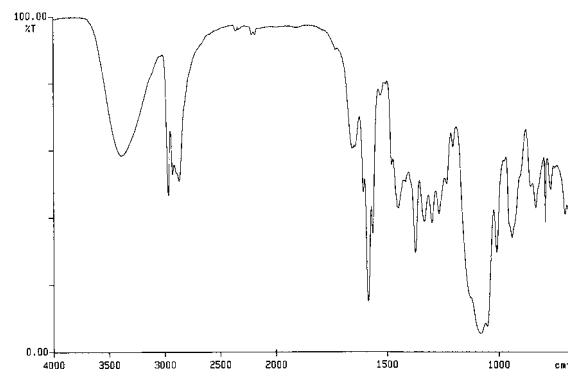
**Figure 7** IR spectrum of the product of the reaction of adenine with PO at the molar ratio 1:1.



**Figure 8** IR spectrum of the product of the reaction of adenine with EO at the molar ratio 1:12.1.

when the molar ratio of oxirane with respect to adenine exceeds  $\sim 4$ . All N—H groups become blocked in the products obtained at the oxirane-to-adenine ratio of 5 in the case of EO or 6 in the case of PO. As follows from the study, the reactivity series of adenine groups in reactions with EO and PO can be written as  $\text{N(9)—H} \gg \text{NH}_2 > \text{OH}$  (with OH from a previously introduced hydroxyalkyl group).

The reaction of adenine with successive moles of oxiranes can also be presented in the form shown in Scheme 1. The reactions lead to trifunctional polyetherols containing a purine ring. The proposed sequence of reactions has been confirmed by examining IR spectra of the products of reaction of adenine with successive moles of EO or PO. The spectrum of adenine was described in detail in the literature.<sup>11</sup> It is worth noticing that the amino group in this compound yields, beside the typical stretching vibrations of  $>\text{N—H}$  bonds in the range  $2800\text{--}3300\text{ cm}^{-1}$ , a convenient diagnostic band from scissoring vibrations at  $1670\text{--}1680\text{ cm}^{-1}$ . The same band is present in the spectra of the product obtained by addition of 1 mol of EO or PO to adenine (Figures 6 and 7). This result confirms that only the group N(9)—H reacts with 1 mol of oxiranes. The bands due to primary amino groups vanish from spectra of products obtained in



**Figure 9** IR spectrum of the product of the reaction of adenine with PO at the molar ratio 1:10.

**TABLE III**  
Physical Properties of Polyetherols Obtained from-in Reactions  
of Adenine with EO or PO

Molar ratio (adenine:oxirane)	Temperature [°C]	Refractive index	Density [g/cm <sup>3</sup> ]	Surface tension ( $\gamma$ [N/m] $\times 10^3$ )
1:16.8 (EO)	20	1.5148	1.2053	—
	30	1.5123	1.1996	—
	40	1.5093	1.1917	—
	50	1.5062	1.1861	56.3
	60	1.5037	1.1795	55.2
	70	1.5010	1.1726	54.6
	80	1.4981	1.1656	53.6
1:10.0 (PO)	20	1.4948	1.0884	—
	30	1.4916	1.0829	—
	40	1.4882	1.0764	—
	50	1.4844	1.0695	—
	60	1.4810	1.0608	35.8
	70	1.4780	1.0518	34.4
	80	1.4742	1.0423	33.6

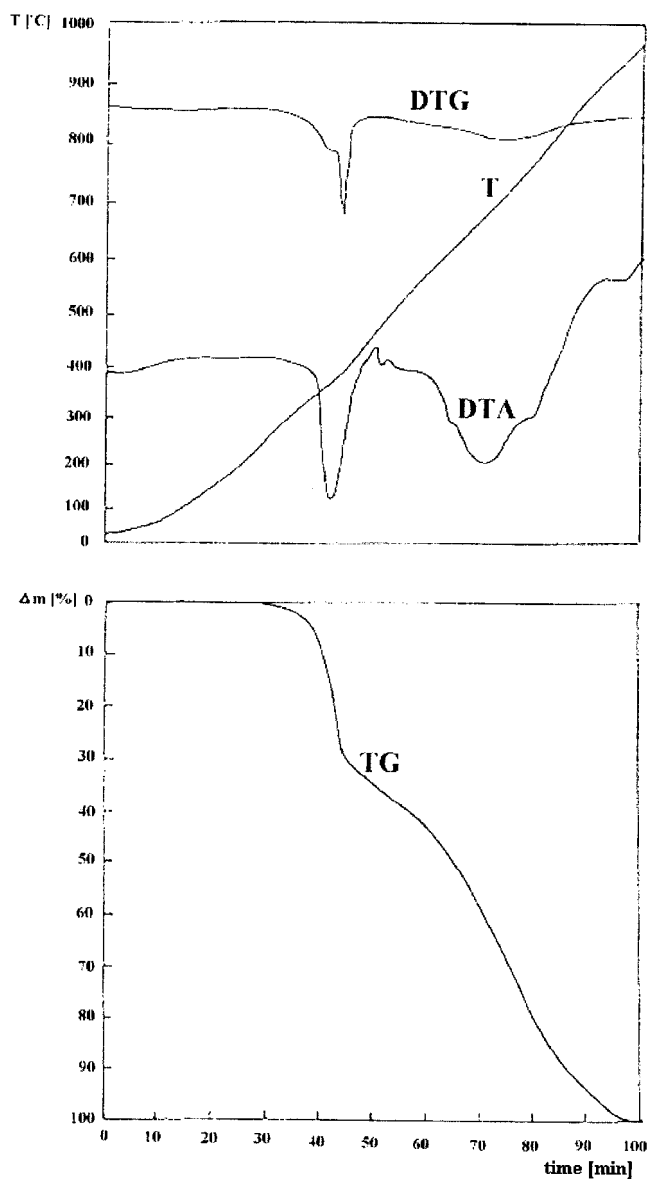


Figure 10 DTA plot for adenine,

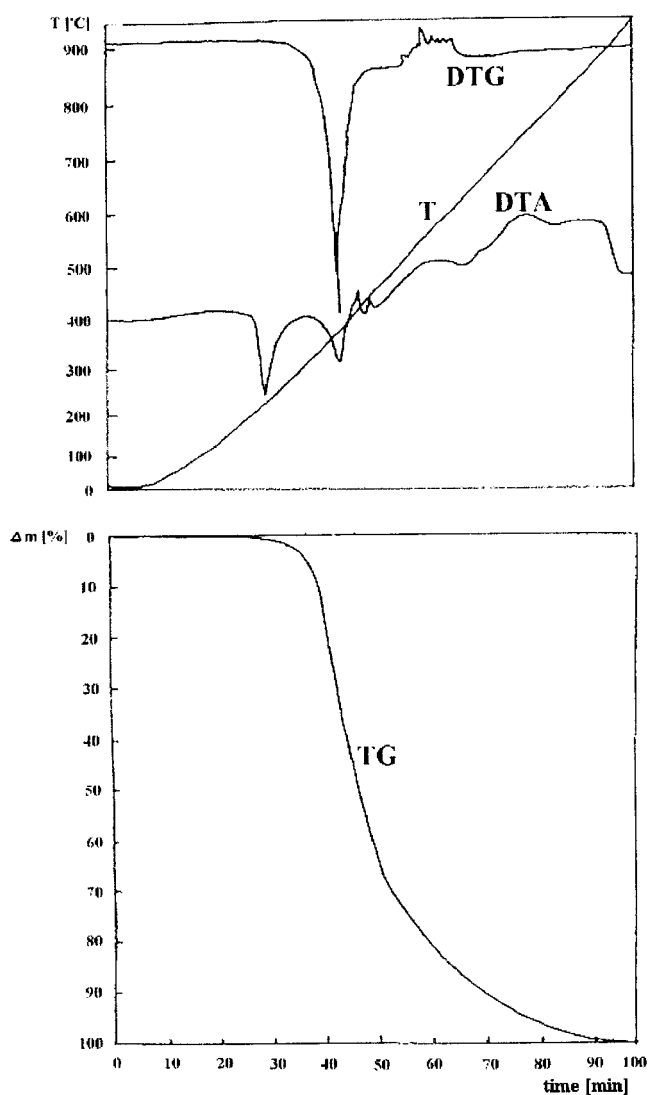


Figure 11 DTA plot for the product of reaction of adenine with EO at the molar ratio 1:1.



the presence of more oxirane (Figures 8 and 9). The shape of bands in the range  $2800\text{--}3300\text{ cm}^{-1}$  changes as well, as a broad peak appears due to associated hydroxyl groups. Also, the band at  $1120\text{ cm}^{-1}$  due to deformational vibrations of hydroxyl groups appears in the spectra. The subsequent addition of oxirane to hydroxy groups is confirmed by the presence of a band at  $1060\text{ cm}^{-1}$  due to ether links.

The products containing a few moles of oxirane per mole of adenine are dark brown solids. As the molar excess of oxirane increases, the products become semi-solid substances. Only the product containing at least 16 mol of EO or 10 mol of PO per mole of adenine becomes liquid.

Some physical properties of the polyetherols, such as density, refractive index, and surface tension, were measured. The results are presented in Table III. Both the refractive indices (1.49–1.51 at room temperature)

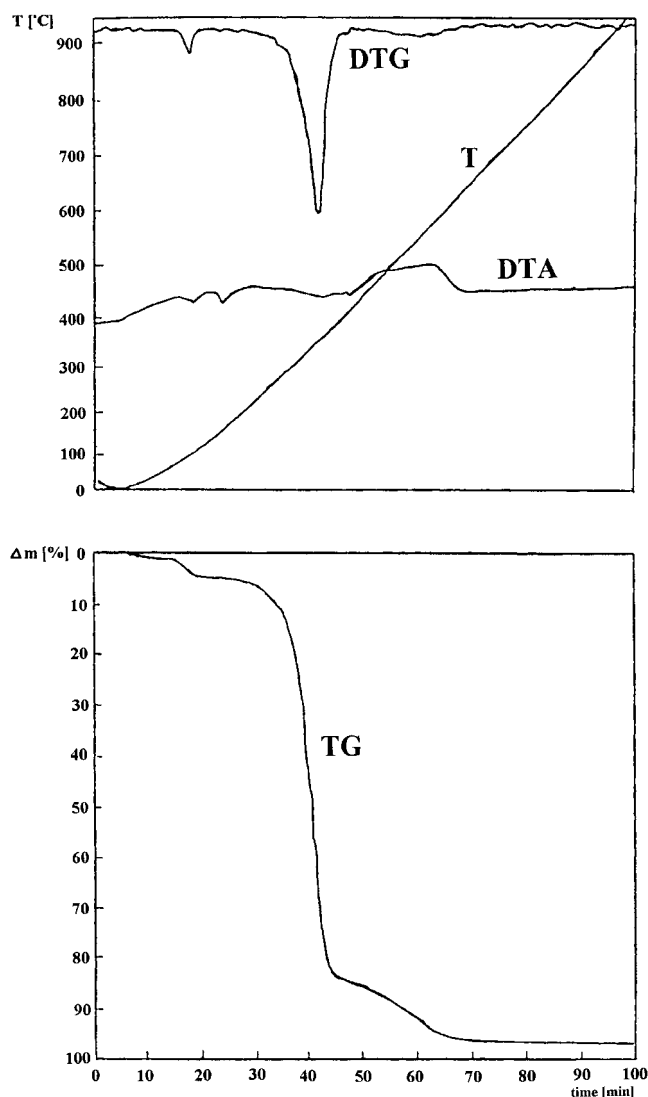


Figure 12 DTA plot for the product of reaction of adenine with PO at the molar ratio 1:1.

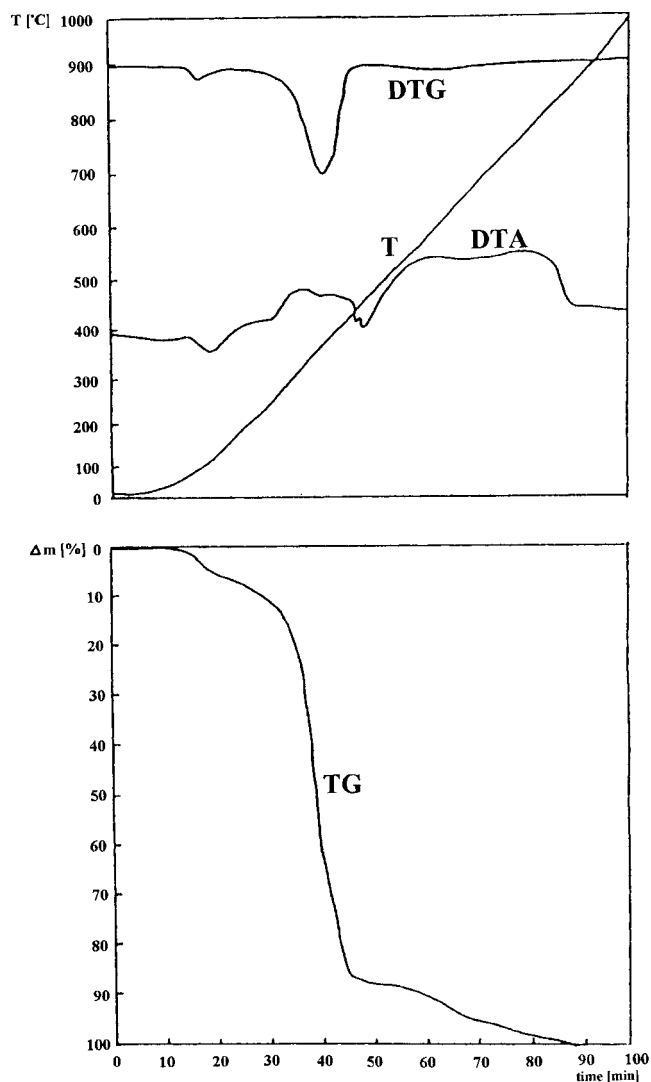


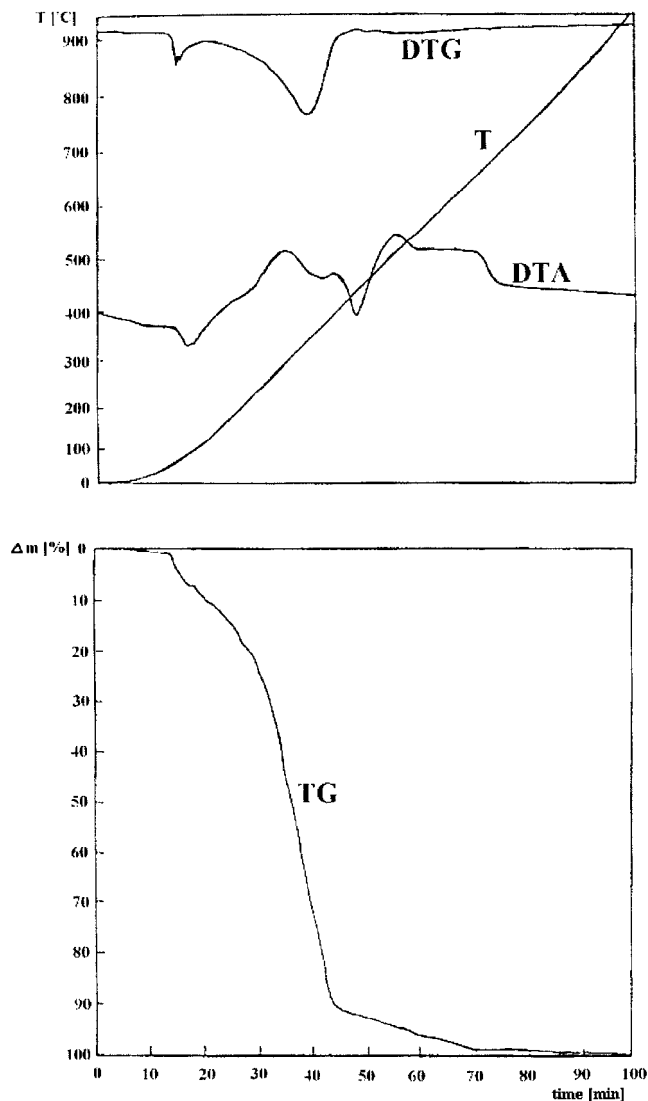
Figure 13 DTA plot for the product of reaction of adenine with EO at the molar ratio 1:12.1.

and surface tensions of the product are quite high. They change with temperature in the typical way.

The polyetherols containing purine rings are expected to exhibit a high thermal stability.<sup>7</sup> To verify the stability of the present products, we recorded DTA, TG, and DTG curves of adenine and the polyetherols. For adenine itself, the first peak on DTA curves (Figure 10) appears at  $360\text{ }^{\circ}\text{C}$  and corresponds to adenine melting point. A small mass reduction follows due to evaporation. Decomposition of the compound takes place at as high a temperature as  $680\text{ }^{\circ}\text{C}$ .

The crystalline product of addition of 1 mol of oxirane to adenine produces two peaks on the DTA curve (Figure 11). The first peak at  $\sim 230\text{ }^{\circ}\text{C}$  is the melting point, and the second peak, accompanied by mass reduction due to decomposition, is at  $\sim 380\text{ }^{\circ}\text{C}$ . Further heating leads to total annihilation of the sample. The product of addition of 1 mol of PO to a mole





**Figure 14** DTA plot for the product of reaction of adenine with PO at the molar ratio 1:10.

of adenine behaves similarly. The melting peak appears at  $\sim 180$  °C and decomposition starts at 350 °C (Figure 12). Two endothermic peaks appear on the

thermal analysis curves of the products of reaction of adenine with more moles of oxirane (Figures 13, 14): one in the range 120–140 °C due to evaporation of the solvent (DMF) not fully removed by distillation, and one at 440–480 °C from polyetherol decomposition. The conclusion is that, indeed, the products of hydroxyalkylation of adenine are thermally stable to temperatures as high as 440–480 °C.

## CONCLUSIONS

In reactions of adenine with an excess of ethylene oxide or propylene oxide, one obtains oligoetherols with purine rings. The oxyethylation reaction starts at the N(9)—H group of adenine, and crystalline 2-(adenin-9-yl)ethanol or 2-(adenin-9-yl)-1-methylethanol can be isolated. In reactions with a higher excess of the oxiranes, the amino group at C(6) of adenine ring also becomes substituted. When the molar excess exceeds 5, in the case of EO, or 6, in the case of PO, the amino group is totally blocked. The reaction leads to trifunctional polyetherols with purine rings. The polyetherols exhibit high thermal resistance and start to decompose at 440 °C.

## References

1. Reymore, H. E.; Carleton, P. S.; Kolakowski, R. A.; Sayigh, A. A. *J Cell Plast* 1975, 11 (6), 328.
2. Moss, E. K.; Skinner, D. L. *J Cell Plast* 1976, 12 (6), 332.
3. Moss, E. K.; Skinner, D. L. *J Cell Plast* 1978, 14 (3), 243.
4. Kucharski, M.; Lubczak, J. *Acta Polym* 1991, 42 (4), 186.
5. Lubczak, J.; Chmiel, E. *Polimery (Warsaw)* 1990, 35 (6), 194.
6. Jonescu, M.; Mihalache, I.; Zugravu, V.; Mihai, S. *Cell Polym* 1994, 13 (1), 57.
7. Cisek-Cicirko, I.; Lubczak, J. *J Appl Polym Sci* 2000, 77, 2667.
8. Brojer, Z.; Hertz, Z.; Penczek, P. *Epoxy resins (in Polish)*; WNT: Warsaw, 1972.
9. Kucharski, M.; Kijowska, D. *J Appl Polym Sci* 2001, 80, 1776.
10. Nowak, M.; Rostkowska, H.; Łapiński, L.; Kwiatkowski, J.; Leszczyński, J. *J Phys Chem* 1994, 98, 2813.
11. Nowak, M.; Łapiński, L.; Kwiatkowski, J.; Leszczyński, J. *J Phys Chem* 1996, 100 (9), 3527.