JOLANTA MAŚLIŃSKA-SOLICH*), EDYTA GIBAS, SYLWIA KUKOWKA

Silesian University of Technology
Department of Physical Chemistry and Technology of Polymers
ul. M. Strzody 9, 44-100 Gliwice, Poland

# The formation of macrocyclic compounds with *O,O*- and *O,N*-acetal units**)

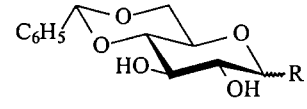
**Summary** — Poly(acetal)s are prepared in polycondensation of methyl α-D-mannopyranoside (**IX**) and terephthalaldehyde (**IV**) or 1,4-bis(formylphenoxy)butanes (**XIV**) catalyzed by acid. The composition highly depends on the reaction conditions, structure of comonomers and nature of catalyst leading to the formation of chiral macrocycles and linear macromolecules. The regioselective polycondensation was examined by $^1$H NMR spectroscopy. The structures of polycondensation products were also identified by electrospray mass spectrometry (ESI-MS) and MALDI-TOF mass spectroscopy. The polycondensation of terephthalaldehyde with 2-amino-2-hydroxymethyl-1,3-propanediol [or 2,2'(1,4-phenylene)-bis-1,3-(4,4-dihydroxymethyl)oxazolidine (bis-oxazolidine)] and 2-amino-2-methyl-1,3-propanediol under acidic catalysts leads to the formation of macrocyclic compounds. ESI-MS measurements were used to study the details of polymer structure and support the nature of oxazolidine-acetal and 2-(1',4'-phenylene)-5-methyl-1-aza-3,7-dioxabicyclo[3.3.0]octane as the repeating units in all macromolecules (both cyclic and linear).

**Key words**: macrocyclic compounds, acetals, oxazolidines, polycondensation, molecular structure, modelling.

The synthesis of large variety of cyclic macromolecules has been self-assembled. The self-assembly of molecular assemblies and supramolecular arrays held together, at least to some extent by non-covalent bonding of molecules (hydrogen bonds, metal-ligand binding, π–π interactions and hydrophobic effects). It is clear from these natural examples that the implication of each individual non-covalent bonding interaction must be considered if efficient and co-operative self-assembly processes are employed in the construction of novel materials. In contrast to these much — studied systems, the self-assembly of synthetic polymers is more complex and immature.

An impressive part of chemistry of carbohydrates has dealt with cyclic acetals (mainly 1,3-dioxanes and 1,3-dioxolanes). Since the early studies by Emil Fischer on the reactions of monosaccharides with aldehydes and ketones, cyclic acetal formation has become one of the most widely used techniques for the selective protection of hydroxyl groups in carbohydrate synthesis.

Alberda van Ekenstein and Blanksma [1] first reported the synthesis of 4,6-*O*-benzylidene-D-glucopyranose in 1906. Today, derivatives of 4,6-*O*-benzylidene-D-glucopyranose [Formula (I)] have received increasing attention as an anti-cancer drug [2] (it has reached the




(I)

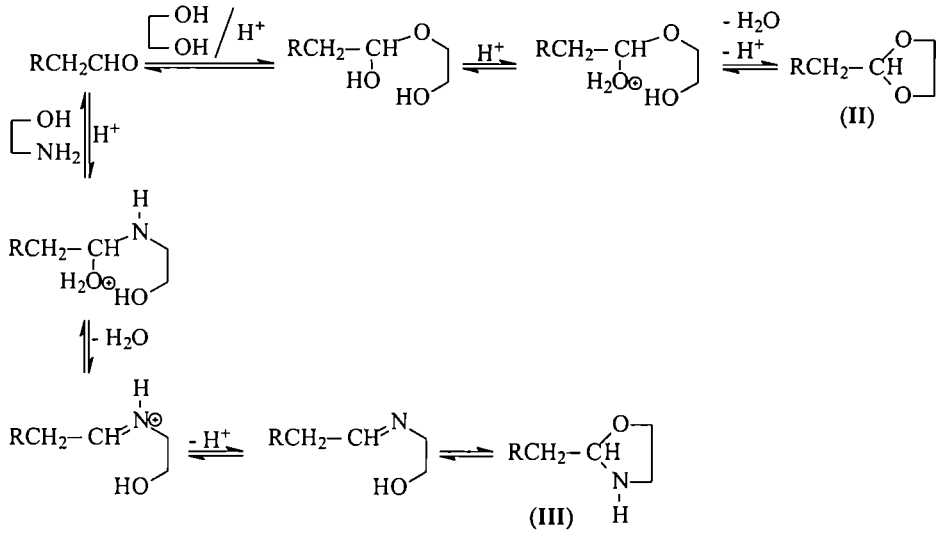
R = -OH, -$OCH_3$, -$OCOC_6H_5$, -$O^-Na^+$, -$O^-Bu_4N^+$

clinical study phase with significant inhibitory action on several types of advanced carcinoma). Another acetals of D-glucose, namely 4,6-*O*-ethylidene- and 4,6-*O*-benzylidene-D-glucopyranose have been shown to interact with the protein, which make the transmembrane D-glucose transport possible [3, 4].

Synthetic polymers combined with carbohydrates are of great interest in the field of medical, biomedical, and ecological applications, so that various types of polymers have been designed and synthesized. Sugar based polymers are generally prepared by polymerization of vinyl sugar, anhydro-sugars, enzyme-mediated synthe-

*) Author, to whom all correspondence should be addressed; e-mail: Jolanta.Maslinska@polsl.pl

**) Paper presented at 47th Polish Chemical Society Congress, Wroclaw, 12—17 September 2004.



*Scheme A. Formation of O,O-acetals (II) and N,O-acetals (III)*

sis of carbohydrate polymers or grafting of sugars onto functionalized synthetic polymers by polymer analogous reaction [5]. They are mainly useful for elucidating the role of carbohydrates in the biochemical processes (in cell recognition processes, for binding of hepatocytes, synthetic antigens *etc.*).

Another strategy was adopted for carbohydrate polymers obtaining, which was the polycondensation. Synthetic polymers containing a sugar residue in the main chain were prepared in polycondensations using several combinations of saccharide monomers and dicarboxylic derivative [6]. Carbohydrates have been derivatized through their hydroxy and amino function groups including *O*- and *C*-glycosides and poly(vinylsaccharides) have been obtained as ethers [7], esters [8], and amides [9]. Kadokawa *et al.* [10] reported a direct polycondensation of D-glucosamine derivatives having a carboxylic acid group using hexachlorotriphosphazene/pyridine system as a condensing agent. Recently, the same authors examined the polycondensation of benzyl 2-amino-2-deoxy-α-D-glucopyranoside hydrochloride with carbon dioxide, which proceeded at amino and primary hydroxy groups regioselectively to give poly(urethane) with glucosamine structure in the main chain [11].

Our group is currently working on synthesis of polymer containing carbohydrate units in the main chain by the polycondensation of dialdehydes with monosaccharides. The advantage of this procedure is that it is a single step process without necessity to use hydroxyl protection group chemistry of sugar molecule. Another interesting aspect of the study would be to obtain structure-property relationships in the reaction of dialdehydes with specific hydroxyl groups of the sugar. It has been demonstrated in our several recent publications that macrocycles and linear macromolecules exist in chain-ring equilibrium.

The chemistry of 1,3-oxazolidines (*O,N*-acetals) has attracted considerable interest both in academic centers and in industry over the last decade. The ring-chain tautomerism of Schiff bases derived from aryl carbonyl compounds and aminoalcohols, as a reversible addition of hydroxyl group to an imine double bond, is already a very well investigated feature [12, 13]. Relatively little is known about ring-chain tautomerism of 1,3-oxazolidin-2-yl units in polymer chain. The tautomeric character of these heterocycles in macromolecules offers a great number of structural possibilities.

This paper will highlight two approaches for the preparation of macromolecules of controlled structure in the polycondensation process of some dialdehydes with carbohydrates and β-amino-alcohols. Our experimental data were divided into two parts: 1) poly(*O,O*-acetals) derived from carbohydrates, 2) poly(*N,O*-acetals) derived from β-aminodiols. The acid catalysts are essential for both types of the acetalization reactions (Scheme A).

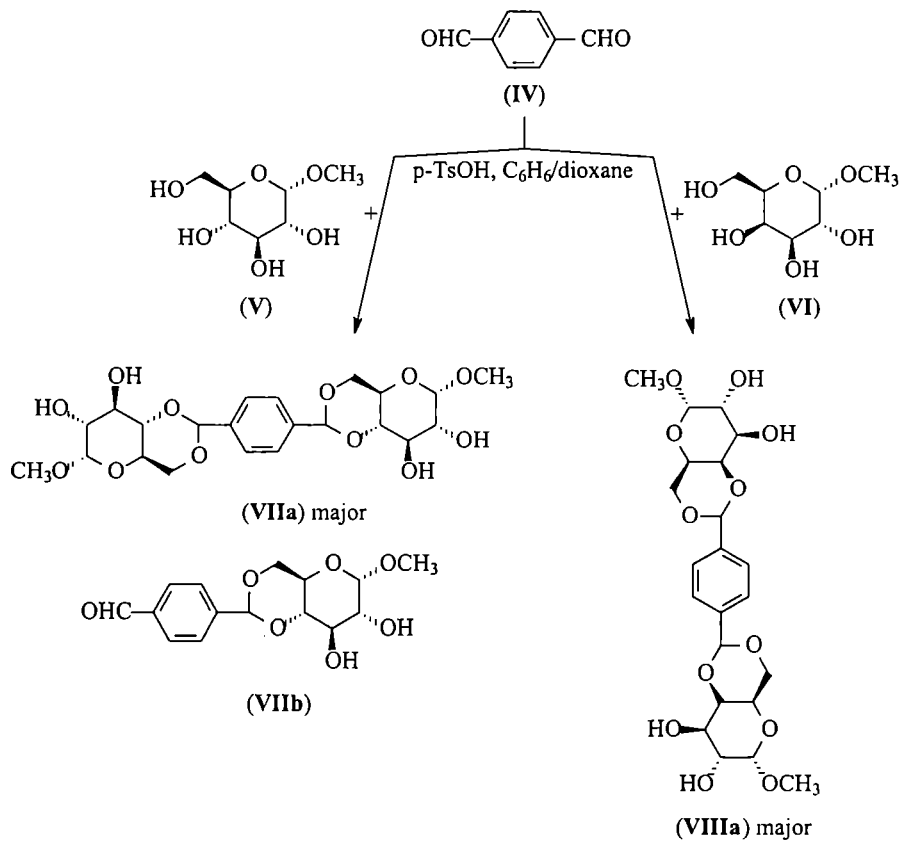
The aim of our work is dealing with the question of how cyclic oligomers with *O,O*- and *O,N*-acetal units can be prepared in concentrated solution on the basis of our research results obtained lately.

The formation of macrocycles in these types of polyreactions can be discussed on the basis of the nature of interaction responsible for self-assembly.

## POLYCONDENSATION OF METHYL D-HEXOPYRANOSIDES WITH DIALDEHYDES

The structure and stereochemistry of polyacetals formed in the acetalization of methyl D-hexopyranosides [methyl-α-D-glucopyranoside (**V**), methyl α-D-galactopyranoside (**VI**), methyl α-D-mannopyranoside (**IX**)] with dialdehydes [terephthalaldehyde and 1,4-bis(formylphenoxy)butanes — (**IV**) and (**XIV**), respectively] were tested (for those formulas see Scheme B, C and D).

The condensation or polycondensation of dialdehyde with methyl D-hexopyranosides [(**V**), (**VI**) and (**IX**)] was

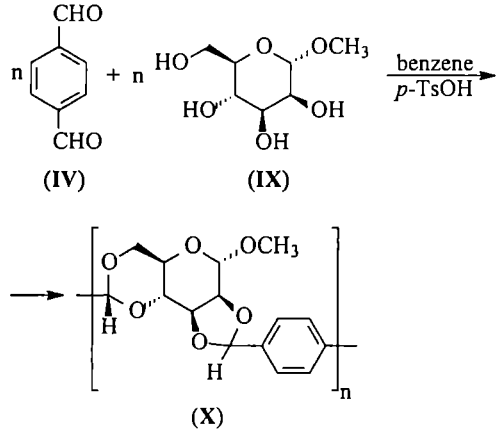



*Scheme B. Condensation of terephthalaldehyde (IV) with methyl α-D-glucopyranoside (V) and methyl α-D-galactopyranoside (VI)*

performed in solution in the presence of catalytic amount of *p*-toluenesulfonic acid (*p*-TsOH) or its complex with poly(4-vinylpyridine) PVP-TsOH and azeotropic removal of water.

Mono- and dicyclic acetals were obtained by reaction of terephthalaldehyde (**IV**) with methyl α-D-glucopyranoside (**V**), or methyl α-D-galactopyranoside (**VI**) (Scheme B) [14]. In the case of the molar ratio 1:2 the major product was cyclic diacetal. $^{1}H$ NMR and $^{13}C$ NMR spectral analyses of the synthesized compounds have shown that the acetals of (**V**) and (**VI**) are diacetals [Formula (**VIIa**) or (**VIIIa**)] in which one molecule of (**IV**) is connected to two molecules of (**V**) or (**VI**). There was no indication of the formation of 2,3:2′,3′-*O*-terephthylidene substituents at carbon C-2 and C-3 of (**V**) or (**VI**). It is likely that the *trans*-disposition of HO-2 and HO-3 in (**V**) or (**VI**) is unfavorable for cyclic formation under acidic conditions. A detailed $^{1}H$ NMR analysis of (**VIIb**) confirmed that the substituent at C-2 (in 1,3-dioxane) is in equatorial orientation with respect to the chair-shaped dioxane ring fused to a tetrahydropyran ring.

For methyl α-D-mannopyranoside, where HO-2 and HO-3 are *cis*, the formations of macromolecules with 5-membered and 6-membered acetal rings were obtained (Scheme C). The evidence for polymeric materials in polycondensation (**IX**) with (**IV**) has been confirmed by SEC analysis. Evidence for the structure of the polymer is demonstrated by NMR spectra [14].




*Scheme C. Polycondensation of terephthalaldehyde (IV) with methyl α-D-mannopyranoside (IX)*

NMR data have been used to establish the configuration of 5-membered acetal ring at C-2 and C-3 and 6-membered acetal ring at C-4 and C-6 of methyl α-D--mannopyranoside units in the polycondensation products. $^{1}H$ NMR spectrum of polymer (**X**) consists of several sets of bands concerning acetal at 6.35—6.28 ppm (H-2 *endo*), 6.0—5.94 ppm (H-2 *exo*), 5.68—5.62 and 5.59—5.47 ppm (4,6-*O*-terephthylidene) and 5.1—4.9 ppm due to anomeric protons. The relative intensities of *endo*-H and *exo*-H (in 1,3-dioxolane) were 1:1. These results confirm the presence of *endo* and *exo* isomers in

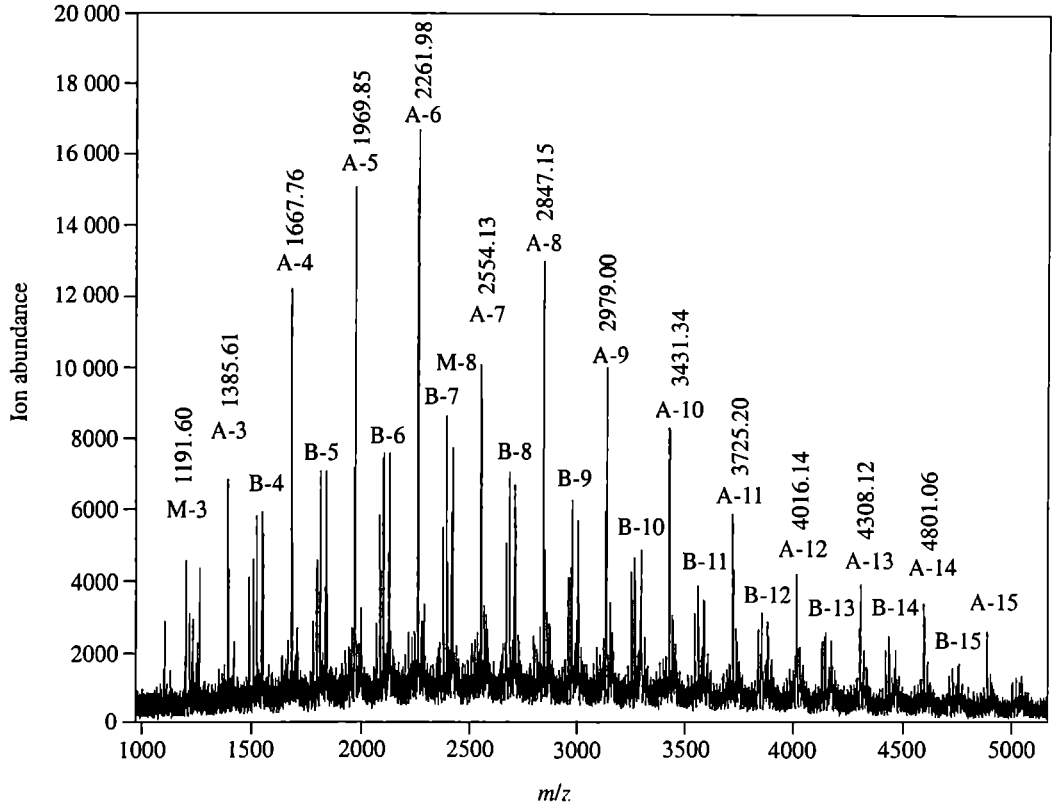
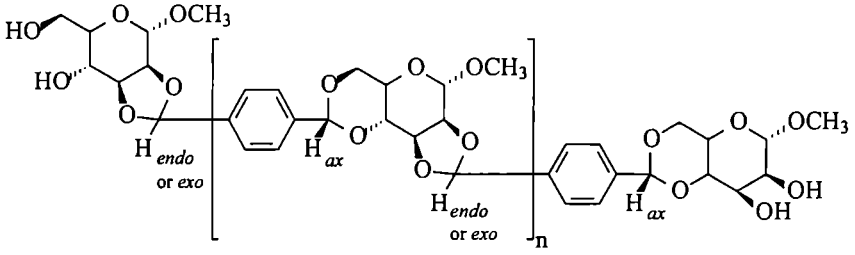
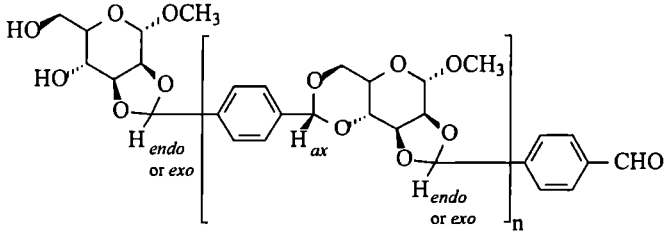



*Fig. 1. MALDI-TOF mass spectrum (linear mode, NaI added) of polycondensation products of (IX) with (IV); A — first series of peaks of Formula (XI), B — second series of peaks of Formula (XII), M — macrocyclic compounds of Formula (XII). Polycondensation conditions: molar ratio of monomers 1:1, catalyst — p-toluenesulfonic acid, benzene/DMSO = 4:1, t = 20 h*

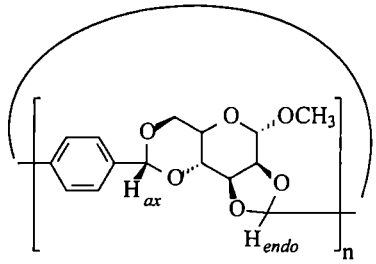


(XI)

where: $H_{ax}$ — axial location of H in comparison with compound



(XII)

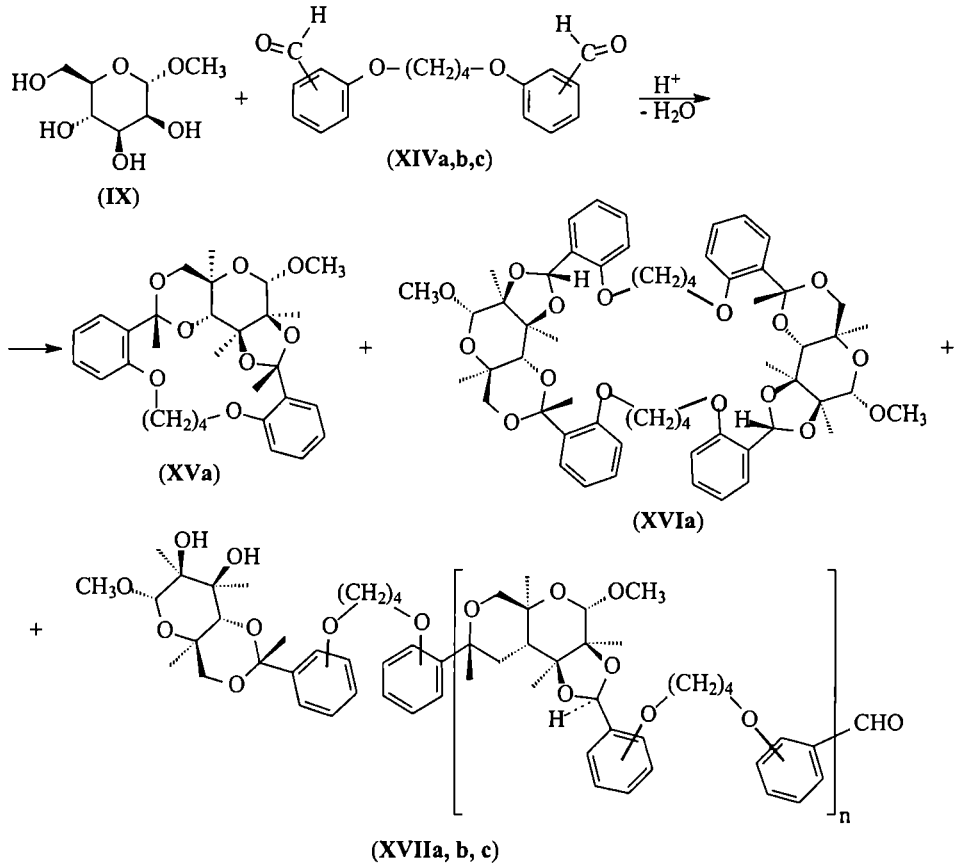


(XIII)

5-membered rings in the polymer chain in approximately equal amounts. Thus, the polycondensation of (IX) with (IV) is generally accompanied by the interaction of terephthylidene substituents at C-2, C-3, and C-4, C-6 of methyl α-D-mannopyranoside moiety in $S_N2$ cyclic transition states.

MALDI-TOF spectrometry has been used for the characterization of subtle details of the molecular structures of these new polymers. As it was shown in MALDI-TOF mass spectra (Fig. 1) the chains were terminated with carbohydrate moieties [first series of peaks A — Formula (XI)] or carbohydrate/1-phenylidene-formyl groups [second series of peaks B — Formula (XII)].

The most abundant peaks are characterized by mass increment of 292 Da from one peak to the next. This mass increment equals the mass of repeating unit in the




*Scheme D. Polyacetalization of methyl α-D-mannopyranoside (IX) with 1,4-bis(formylphenoxy)butanes (XIV); a — 2-formyl, b — 3-formyl, c — 4-formyl*

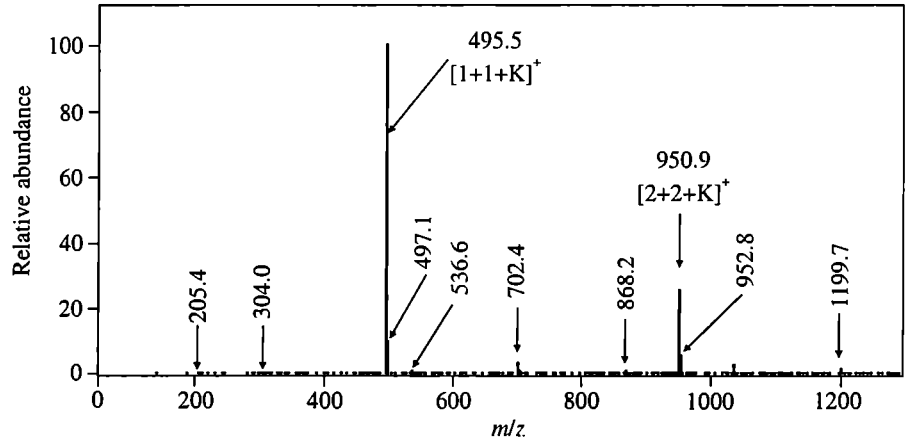



*Fig. 2. ESI-MS spectrum (in positive ion mode) of macrocycles [1+1+K]+ (XVa) and [2+2+K]+ (XVIa)*

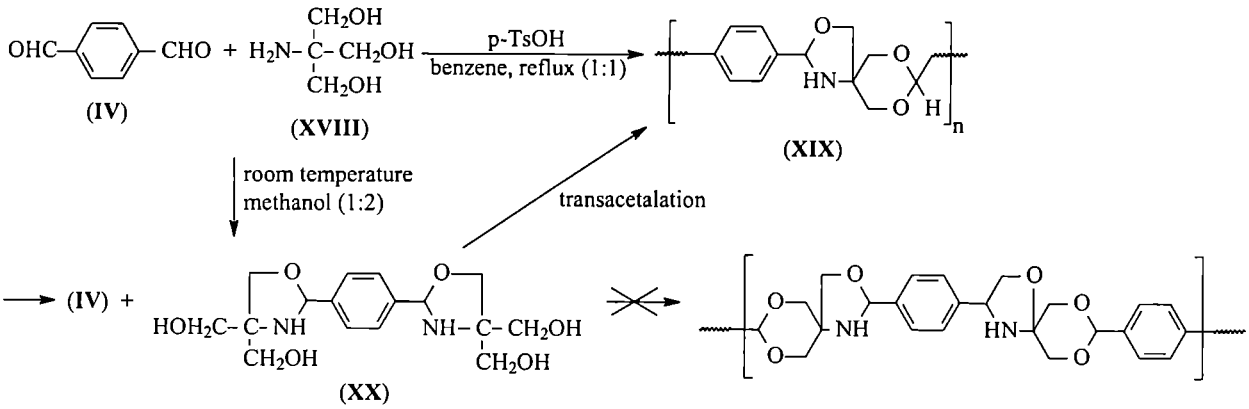
poly(methyl 2,3:4,6-di-*O*-terephthalidene-α-D-mannopyranoside). The third series of peaks correspond to polyacetals with macrocyclic structure namely [Formula (**XIII**)].

The molecular weights of these macromolecules were in the range of 1000—7000 Da.

In the polycondensation of (**IX**) with 1,4-bis(formylphenoxy)butanes (**XIV**) (containing alkoxy [-O(CH$_2$)$_n$O-] spacer) the presence of linear macromolecules and macrocycles as reaction products was found (Scheme D) [15—18].

From the point of view of self-assembly organization particularly noteworthy is the polycondesation of (**IX**) with 1,4-bis(2-formylphenoxy)butane (**XIVa**) because under selected reaction conditions the dominant products obtained are macrocycles [1+1] (**XVa**) and [2+2] (**XVIa**).

Detailed $^1$H NMR and X-ray [15] analyses of macrocycle compound (**XVa**) confirmed that the conformation of 5-membered 1,3-dioxolane rings are different in two symmetry-independent molecules: in one of the molecules it is closed to an envelope, while in the other one to




*Scheme E. Condensation and polycondensation of terephthalaldehyde (IV) with 2-amino-2-hydroxymethyl-1,3-propanediol (XVIII)*

a distorted half chair. Both symmetry-independent molecules are H-*endo* isomers. Whereas the substituent at C-2 (in 1,3-dioxane) is in equatorial orientation with respect to the chair-shaped dioxane ring fused to a tetrahydropyran ring [15].

Moreover the presence of macrocycles were detected by Electrospray Ionization (ESI) mass spectrometry (MS) (Fig. 2). ESI-MS analyses of (**XV**) revealed the presence of potassium adduct ions showing $m/z$ values 495.5 and 950.9 that correspond to the individual macrocycles $[1+1+K]^+$ (**XVa**) and $[2+2+K]^+$ (**XVIa**).

It was shown that the polycondensation of (**IX**) with 1,4-bis(3-formylphenoxy)butane (**XIVb**) or 1,4-bis(4-formylphenoxy)butane (**XIVc**) led only to the formation of linear polymers [16]. More detailed information will be published [18].

From the data presented here it can be concluded that direct acid catalyzed acetalization of two bifunctional building block methyl α-D-mannopyranoside and 1,4-bis(2-formylphenoxy)butane is driven to macrocycles [1+1] (**XVa**) and [2+2] (**XVIa**) and the linear macromolecules. The formation of (**XVa**) and (**XVIa**) may need thermodynamically rather than kinetically controlled conditions for a given reaction. Thus, although there are theoretically four possible intramolecular condensations of (**IX**) with (**XIVa**), only one compound (**XVa**) (highly favored H-2 *endo*-5-membered ring and H-2 *axial*-6--membered ring) is produced. Obviously, the possibility of hydrogen bond formation between neighboring molecules is responsible for the occurrence of macrocyclic form in this polycondensation process. Moreover, the hydroxy groups are organized in large hydrogen bonding so appropriate nature and concentration of acid catalyst arranged the building blocks for their self-organization.

## POLYCONDENSATION OF β-AMINODIOLS WITH DIALDEHYDES

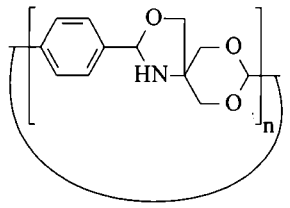
It has been demonstrated in [13, 19, 20] that β-aminodiols (*e.g.* 2-amino-2-hydroxymethyl-1,3-propanediol (**XVIII**), 2-amino-2-methyl-1,3-propanediol (**XXIII**) with terephthalaldehyde (**IV**) in the presence of acidic catalysts [*p*-TsOH, PVP-TsOH and (1S)-(+)-camphor-10-sulfonic acid (CSA)] with continuous removal of water have undergone a stepwise polycondensation to form the polymers (**XIX**) characterized by molecular weights in the range of 850—9600 Da (Scheme E).

The alternating nature of equimolar amounts of oxazolidine and the cyclic acetal of (**IV**) in these macromolecules was supported by spectroscopic analysis. However NMR analysis is an important tool in the studies on structure of polymer chain but only ESI-MS investigation let determine subtle differences in the chemical structure of end groups [21].

ESI-MS analysis revealed the presence of protonated molecules with $m/z$ values corresponding to three kinds of macromolecular chains containing different end groups, *i.e.*, CHO and OH groups (A), only OH groups (B), and oligomers with no end-groups, *i.e.*, macrocyclic compounds (C). The number of repeating units in $MH^+$ ions varied from A-n = 3—8, B-n = 2—3, C-n = 3—5. This spectrum reveals the presence of macrocyclic compounds located at $m/z$ 658.6 $[C\text{-}3+H]^+$, 877.6 $[C\text{-}4+H]^+$, 1096 $[C\text{-}5+H]^+$ as minor reaction products. The signals in the spectrum show a peak-to-peak mass increment of 219 Da, which is equal to the molecular weight of monooxazolidine as the repeating unit in macromolecule [19].

The dominant macrocyclic product has been observed when the reaction of (**IV**) with 2,2'-(1,4-phenylene)-bis-1,3-(4,4-dihydroxymethyl)oxazolidine (bis--oxazolidine) was carried out in the presence of CSA as catalyst. ESI-MS spectrum consists of several sets of peaks produced by cyclic oligomers. This spectrum indicates the presence of one set of $[C\text{-}n+H]^+$ ions with $m/z$ 658.5 (C-3), 877.6 (C-4), 1096 (C-5), and 1315 (C-6), values corresponding to the individual macrocycles with 3 to 9 monomer units in the ring [Formula (**XXI**)]. This ESI-MS spectrum and fragmentation pattern were described in [19].

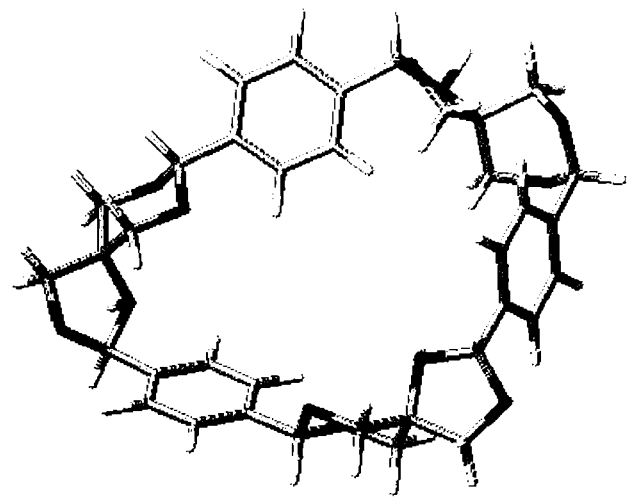
To have excluded intramolecular condensation hydroxyl and aldehyde groups at ends of chains and conse-



(XX)

where: n = 3—9

quently cyclization before ionization inside MS instrument hydrogenation by sodium borohydride of aldehyde groups of polymer [product of polycondensation of (**IV**) with bis-oxazolidine] to alcohol groups was carried out. Examination of ESI-MS spectrum of the resulting reduced polymer revealed the presence of only one set of sodium adduct ions, with $m/z$ values of 680.5 $[C\text{-}3+Na]^+$, 899.5 $[C\text{-}4+Na]^+$, 1118.6 $[C\text{-}5+Na]^+$, 1337.6 $[C\text{-}6+Na]^+$, 1557.5 $[C\text{-}7+Na]^+$, 1775.0 $[C\text{-}8+Na]^+$, and 1994.9 $[C\text{-}9+Na]^+$, which correspond to the individual



(XXII)

where: blue = C, deep blue = N, grey = H, red = O

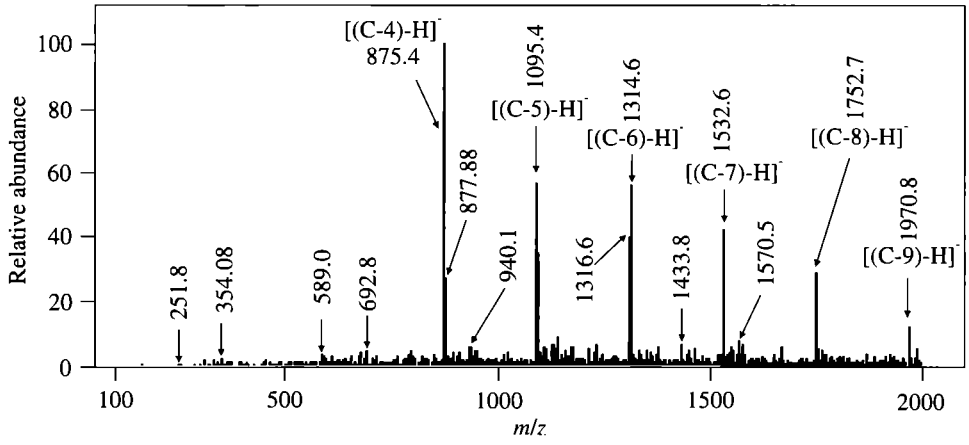



*Fig. 3. ESI-MS spectrum (in negative ion mode) of macrocyclic compound (**XIX**)*

macrocycles [19]. The macrocycles $[C\text{-}n\text{-}H]^-$ were also detected by using the negative ion mode (Fig. 3).

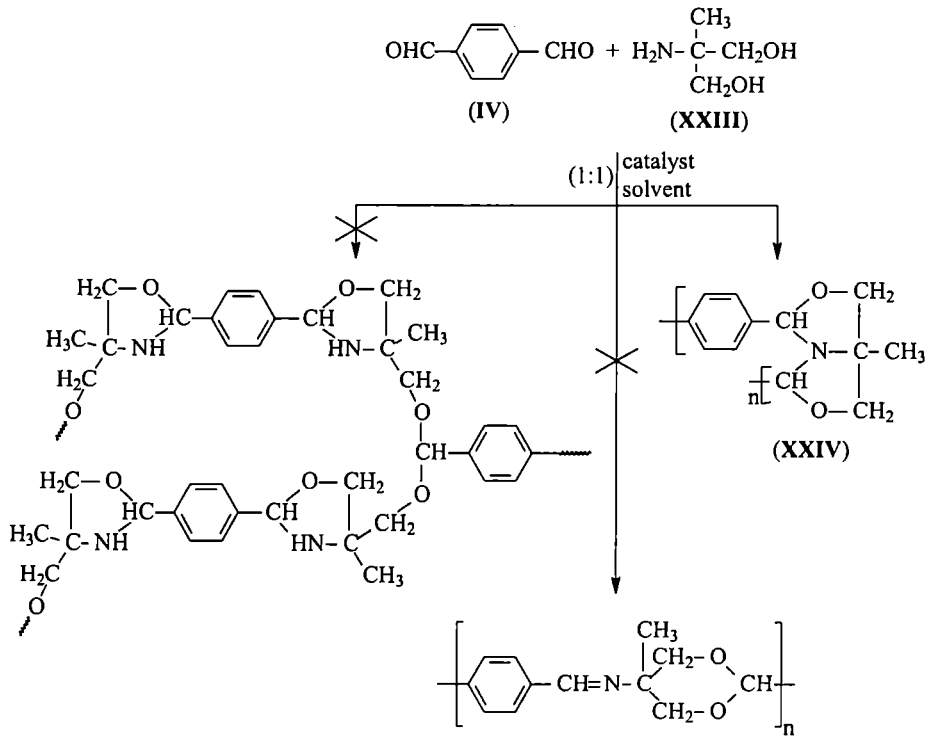
Previously described fragmentation ions at macrocyclic structure are formed by expulsion of a repeating unit 219 Da [19]. It can be seen that the mass spectral fragmentation fall into expected oxazolidine-dioxane pattern.

The peaks in the spectrum show a peak-to-peak mass increment of 219 Da, which corresponds to molecular mass of mono-oxazolidine as the repeating unit in the macrocycles. It was thus confirmed by ESI-MS that the polycondensation of (**IV**) with bis-oxazolidine to form cyclic and linear polymer occurs only *via* *O,N*-transacetalation of bis-oxazolidine into mono-oxazolidine, followed by its homopolycondensation with simultaneous cyclization (see Scheme D).

In this work a high tendency to form alternating 1,3-oxazolidinyl-1,3-dioxan-2-yl-units in the linear and cyclic macromolecules is shown. Molecular modelling using the CHEM SKETCH program allowed us to observe the skeleton built with 1,3-dioxane ring existing in chair form and 1,3-oksazolidine ring as an envelope; for example Formula (**XXII**) = cyclic trimer 3D from (**IV**) and (**XVIII**). The *trans* diposal (H-2)-NH can also be the result of a strong anomeric effect over the bond sequence (N-1)-(C-2)-(O-3).

However, the polycondensation of (**IV**) with 2-amino-2-methyl-1,3-propanediol (**XXIII**) (for Formula see Scheme F) leads to the formation of macrocyclic compounds and linear polymers showing different structures of repeating units (**XXIV**) (for Formula see Scheme F). $^1H$ NMR exhibits several sets of peaks centered at 10.00 (CHO); 7.53; 7.34; 7.10 (aromatic protons), 5.55 and 5.24 (OCHN), 4.10; 3.83; 3.69 ($CH_2O$), 1.41 and 1.23 ($CH_3$) ppm. The differences in chemical shift of methyl protons seem to be due to their *cis* (77 %) and *trans* (23 %) orientation with respect to 1,4-phenylene substituent in the oxazolidine ring. On the basis of $^1H$ NMR spectral analysis it was shown that the polycondensation products contained one molecule of (**IV**) and one molecule of (**XXIII**) in the repeating units of the macromolecule (Scheme F).

In order to gain more detailed insight into the structure of a polymer derived from (**IV**) and (**XXIII**) ESI-MS




*Scheme F. Polycondensation of (IV) with 2-amino-2-methyl-1,3-propanediol (XXIII)*

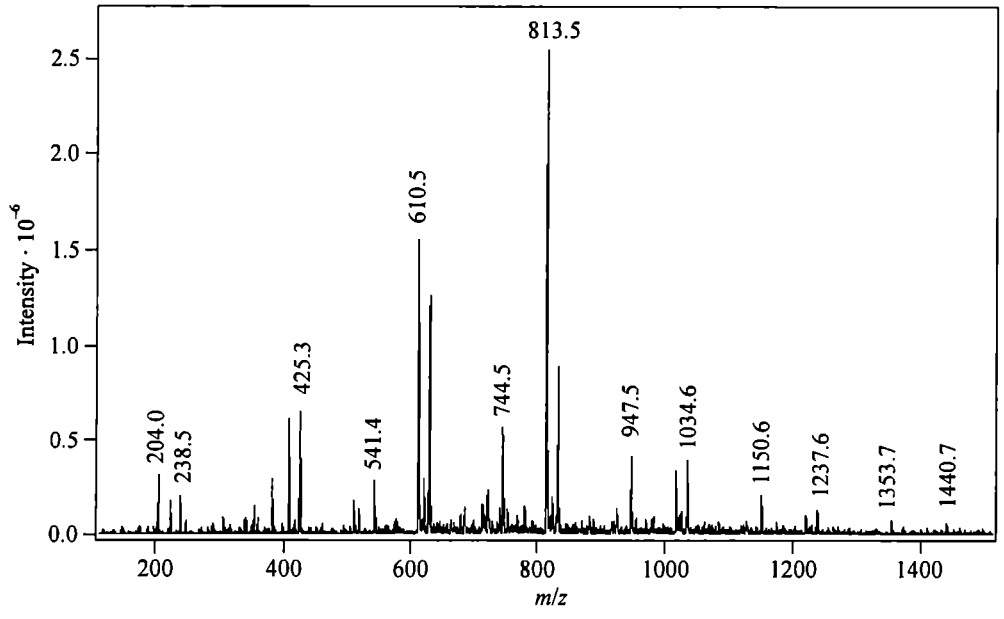
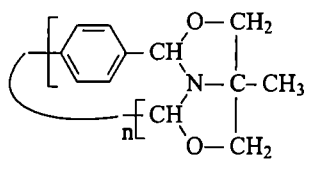
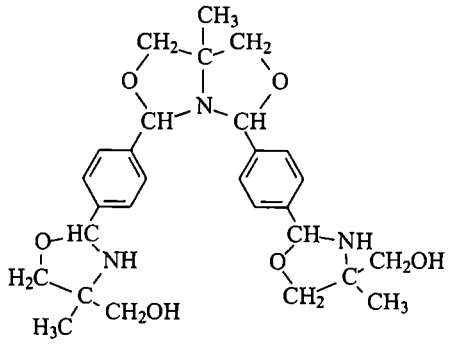



*Fig. 4. ESI-MS spectrum (in positive ion mode) of macrocyclic compounds (XXIV)*

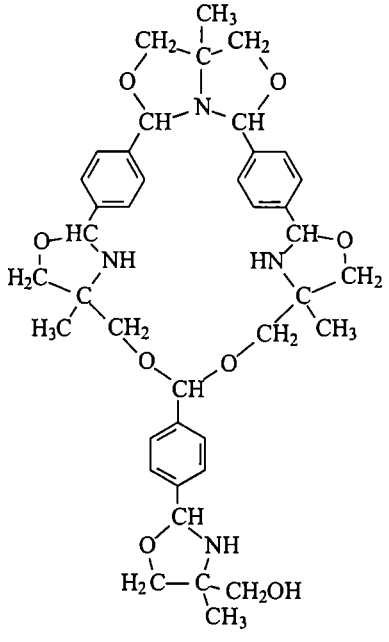
has been performed. Analysis of ESI-MS spectrum revealed the presence of proton ion adducts of the macromolecules with $m/z$ values corresponding to three kinds of macromolecular chain containing different end groups, *i.e.*, CHO plus and OH in group (structure A), only CHO groups (structure B), and macrocyclic compounds (structure C). The signals in the spectrum show a peak-to-peak mass increment of 203 Da, which corresponds to the molecular weight of 2-(1',4'-phenylene)-5--methyl-1-aza-3,7-dioxabicyclo[3.3.0]octane as the repeating unit in all compounds. This spectrum displays also the presence of proton ion adducts of macrocyclic compounds with $m/z$ values corresponding to C-n = 2—5 [Formula (**XXV**)]. The most abundant signal observed for these macrocyclic compounds was located at $m/z$ 813.5 and was assigned as the tetramer $[C\text{-}4+H]^+$. This spectrum reveals also the presence of macrocyclic compounds located at $m/z$ 204.0 $[C\text{-}1+H]^+$, 406.5 $[C\text{-}2+H]^+$, 610.5 $[C\text{-}3+H]^+$ and 1015.5 $[C\text{-}5+H]^+$. The sample obtained in the presence of CSA as a catalyst shows



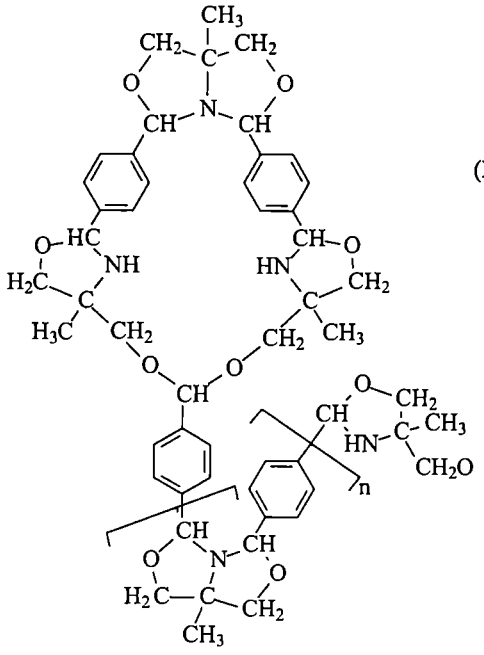
n = 2—5 **(XXV)**



**(XXVI)**



**(XXVII)**



**(XXVIII)**

n = 1—5

rather high relative abundance of oligomers with no end groups, *i.e.*, macrocyclic compounds (structure C) as shown in Fig. 4 [20].

The synthesis of oligomeric compounds was realized by condensation of (**IV**) with (**XXIII**) in molar ratio 1:1.6 (excess of aminodiol) under acidic conditions (PVP-TsOH) and yielded a mixture of products, for which NMR spectra were difficult to be interpreted. However, ESI-MS spectrum reveals only the presence of the sodium ion adducts of compound of structure D {Formula (**XXVI**), $[D+Na]^+$} and of the macrocyclic species of structure E {Formula (**XXVII**), $[E+Na]^+$} and structure F-n {Formula (**XXVIII**), $[(F\text{-}n)\text{-}Na]^+$}.

ESI-MS spectrum (Fig. 5) shows the peaks corresponding to cyclic oligomers located at $m/z$ 510.4 $[D\text{-}H]^-$, 713.4 $[E\text{-}H]^-$, 916.3 $[(F\text{-}1)\text{-}H]^-$, 1119.4 $[(F\text{-}2)\text{-}H]^-$, 1322 $[(F\text{-}3)\text{-}H]^-$, 1525 $[(F\text{-}4)\text{-}H]^-$ and 1728 $[(F\text{-}5)\text{-}H]^-$. The mass

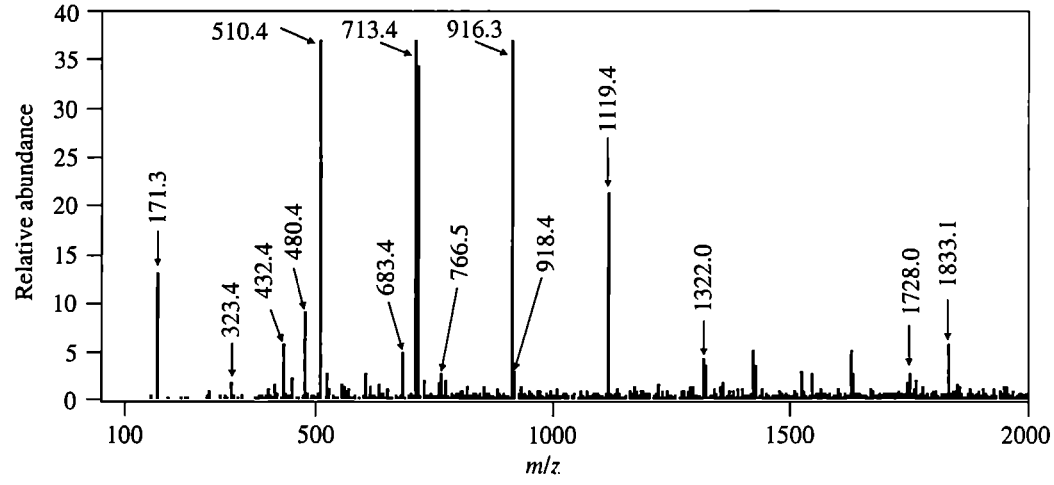
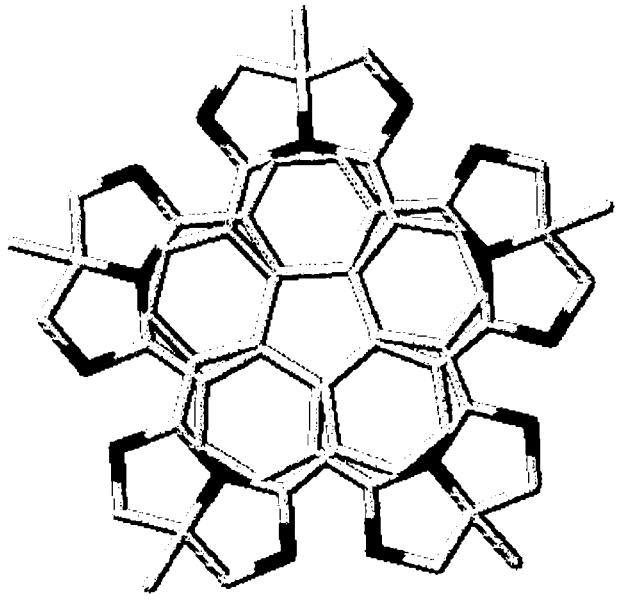
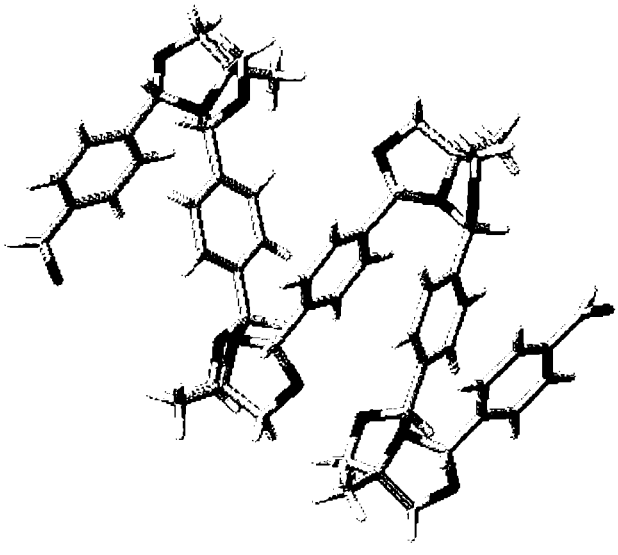



*Fig. 5. ESI-MS spectrum of macrocyclic compound in negative ion mode*



(XXIX)

where: blue = C, deep blue = N, grey = H, red = O



(XXX)

where: blue = C, deep blue = N, grey = H, red = O

difference between successive $m/z$ values of sodium adduct ions of molecules F-n is again equal to 203 Da. In order to gain better insight into the behavior of such compounds, we also performed ESI-$MS^2$ analysis [20], and this confirmed our conclusions described above.

It was shown that polycondensation products of (**IV**) with (**XXIII**) exhibit a high tendency to form alternating 2-(1',4'-phenylene)-5-methyl-1-aza-3,7-dioxabicyclo[3.3.0]octane units in both the linear and cyclic macromolecules. An examination of molecular models of 2,8-diphenyl-5-hydroxymethyl-1-aza-3,7-dioxabicyclo[3.3.0]octane showed that *cis*-fusion of oxazolidine rings was highly favored over the considerably more strained *trans*-fusion.

Molecular modelling using the CHEM SKETCH program allowed us to observe a number of flexible conformations upon pseudo-rotation occurring at each monomeric unit in both chain and cyclic macromolecules. For example we can see cyclic pentamer 2D [Formula (**XXIX**)] and cyclic tetramer 3D [Formula (**XXX**)].

It is apparent that the conformer in both linear and cyclic macromolecules, arising from *cis*-fusion of oxazolidine rings with both 1,4-phenylene substituents in a pseudo-equatorial orientation, would be highly favored over other more strained conformations. Moreover, a self-assembling action of these macrocyclic species can be responsible by combination of the anomeric effect in 1-aza-3,7-dioxabicyclo[3.3.0]octane skeleton and $\pi$–$\pi$ interactions between 1,4-phenylene rings. The zig-zag configurations of linear macromolecules with 1-aza-3,7-dioxabicyclo[3.3.0]octane repeating units can be mainly stabilized by large $\pi$–$\pi$ interactions.

## CONCLUSIONS

In the preceding paper, by means of representative examples, we have attempted to discuss the polycondensation forming of *O,O*- and *O,N*-acetal units in the macrocyclic and linear form. It was demonstrated that methyl α-mannopyranoside with terephthalaldehyde under acidic catalyzed polycondensation forms mainly linear macromolecules due to the strong steric hindrance. Contrary to (**IV**), 1,4-bis(2-formylphenoxy)butane with (**IX**) under the same reaction conditions yields macrocyclic compounds [1+1] and [2+2].

Polycondensations of (**IV**) with 2-amino-2-hydroxymethyl-1,3-propanediol [or 2,2'(1,4-phenylen)-bis-1,3--(4,4-dihydroxymethyl)oxazolidine (bis-oxazolidine)] and 2-amino-2-methyl-1,3-propanediol demonstrated high tendency to the cyclizations. ESI-MS measurements were used to study the details of polymer structure and support the nature of 1,3-oxazolidine-1,3-dioxan-2-yl and 2-(1',4'-phenylene)-5-methyl-1-aza-3,7-dioxabicyclo[3.3.0]octane as the repeating units in all macromolecules (both cyclic and linear ones). The ability of these kinds of macromolecules to self-organize may be of importance for the development of new materials and also for a better understanding of the high level of differentiation and functionalization realized in *O,O*- and *O,N*-acetal systems.

## REFERENCES

1. Ekenstein W. A., Blanksma J. J.: *Recl. Trav. Chim. Pay--Bas* 1906, **25**, 153.
2. Barili P. L., Berti G., Catelani G., Cini C., D'Andrea F., Mastrorilli E.: *Carbohydr. Res.* 1995, **278**, 43.
3. Barnett J. E. G., Holman G. D., Munday K. A.: *Biochem. J.* 1973, **131**, 211.

4. Desruet M. D, Morin Ch., Ogier L.: *Carbohydr. Res.* 1997, **225**, 43.
5. Varma A. J., Kennedy J. F., Galgali P.: *Carbohydr. Polym.* 2004, **56**, 429 and literature cited therein.
6. Thiem J., Bachmann F.: *Makromol. Chem.* 1993, **194**, 1035.
7. Deffieux A., Fanton E., Fayet C., Fontanille M., Gelas J., Jhurry D.: *Carbohydr. Res.* 1992, **226**, 377.
8. Kossmehl G., Volkkheimer J.: *Liebigs Ann. Chem.* 1991, **10**, 1079.
9. Klein J., Kowalczyk J., Kunz M.: *Makromol. Chem.* 1990, **191**, 517.
10. Kadokawa J., Kato M., Kobayashi N., Karasu M., Tagaya H., Chiba K.: *Macromol. Rapid Commun.* 1994, **15**, 971.
11. Kadokawa J., Horiguchi T., Sunaga E., Karasu M., Tagaya H., Chiba K.: *Acta Polymer.* 1997, **48**, 310.
12. Maiereanu C., Darabantu M., Plé G., Berghian C., Condamine E., Ramondenc Y., Silaghi-Dumitrescu I., Mager S.: *Tetrahedron* 2002, **58**, 2681 and literature cited therein.
13. Maślińska-Solich J., Kudrej E.: *Design. Monom. Polym.* 2003, **6**, 31.
14. Maślińska-Solich J.: *Macromol. Biosci.* 2001, **1**, 312.
15. Maślińska-Solich J., Kuźnik N., Kubicki M., Kukowka S.: *Chem. Commun.* 2002, 984.
16. Maślińska-Solich J., Kukowka S.: *Macromol. Symp.* 2004, **210**, 67.
17. Maślińska-Solich J., Kukowka S.: *Macromol. Biosci.* 2003, **4**, 421.
18. Maślińska-Solich J., Kukowka S.: *Polimery (in preparation).*
19. Maślińska-Solich J., Kudrej-Gibas E.: *Rapid Commun. Mass Spectrom.* 2003, **17**, 1769.
20. Maślińska-Solich J., Kudrej-Gibas E.: *Rapid Commun. Mass Spectrom.* 2004, **18**, 2628.
21. Adamus G., Kowalczuk M.: *Polimery* 2001, **48**, 501.