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Some atomic spectrometric determinations of metals in aliphatic polyester and polycarbonate biomedical polymers

Summary — Contents of Al, Zn, Sn and Cr have been investigated in several aliphatic polyesters and polycarbonates obtained in ring opening polymerization and copolymerization of heterocyclic monomers in the presence of coordination catalytic systems with these metals. The metals were reliably determined using spectroscopic atomic techniques: flame atomic absorption spectrometry (FAAS), electrothermal atomic absorption spectrometry (ETAAS) and inductively coupled plasma optical emission spectrometry (ICP-OES). Commercial materials like NatureWorks® polylactide, poly(propylene carbonate) and medical sutures (*e.g.* Dexon®, Vicryl®) were also tested. The results are discussed in terms of applicable catalytic systems for the syntheses of biodegradable polymers, which are sufficient to reach metal concentrations specified in European Pharmacopoeia.
Key words: aliphatic polyesters, aliphatic polycarbonates, biomedical polymers, atomic spectrometry, metals, coordination catalytic systems.

OZNACZANIE ZAWARTOŚCI METALI W BIOMEDYCZNYCH ALIFATYCZNYCH POLIESTRACH I POLIWĘGLANACH Z WYKORZYSTANIEM NIEKTÓRYCH METOD SPEKTROSKOPII ATOMOWEJ
Streszczenie — Zbadano zawartość Al, Zn, Sn and Cr w różnych alifatycznych poliestrach i poliwęglanach, otrzymanych w procesach homo- i kopolimeryzacji z otwarciem pierścienia monomerów heterocyklicznych (L-laktydu, tlenku propylenu, węglanu etylenu) niekiedy z udziałem CO_2 wobec katalitycznych układów koordynacyjnych obejmujących te metale (tabela 6). Zawartość metali określano technikami spektroskopii atomowej: atomowej spektrometrii absorpcyjnej z atomizacją w płomieniu (FAAS, tabela 2), atomowej spektrometrii absorpcyjnej z atomizacją elektrotermiczną (ETAAS, tabele 3 i 4) oraz spektrometrii emisji optycznej ze wzbudzeniem w indukowanej plazmie (ICP-OES, tabela 5). Odpowiednie oznaczania przeprowadzono również w odniesieniu do materiałów handlowych: produktu NatureWorks® typu PLA, poli(węglanu propylenu) oraz nici chirurgicznych Dexon® i Vicryl®. Przedyskutowano wyniki analiz z punktu widzenia spełnienia warunków dotyczących dopuszczalnej, określonej w Farmakopei Europejskiej, zawartości metali w polimerach biomedycznych otrzymywanych w obecności badanych układów katalitycznych.
Słowa kluczowe: poliestry alifatyczne, poliwęglany alifatyczne, polimery biomedyczne, spektroskopia atomowa, metale, koordynacyjne układy katalityczne.

Catalytic ring opening polymerization of cyclic esters and carbonates has become the object of intensive academic and industrial studies with respect to their practical applications in the syntheses of biodegradable materials. Most of the recent efforts is focused on L-lactide polymers which are very promising candidates for manufacturing of disposal dishes, food packings and other products that can be catabolized under natural environment [1—4]. It is also known that several polymers based on lactides, glycolide, ε-caprolactone and trimethylene carbonate are extremely useful for various biomedical and pharmaceutical applications in terms of their low toxicity and adjustable rate of biodegradation in living organisms. The typical examples are bioresorbable sutures, implants and carriers for control drug release [5—13]. The active site in a polymerization catalyst comprises a metal atom (Mt) surrounded by ligands, one of which (X) forms a covalent active bond (Mt-X) with this metal. A characteristic feature of the propagation step is the coordination of the monomer (M) at the metal center before its insertion into the reactive covalent bond [eq. (1)].

$$Mt-X + M \longrightarrow Mt-X \longrightarrow Mt-M-X \qquad (1)$$
$$\uparrow$$
$$M$$
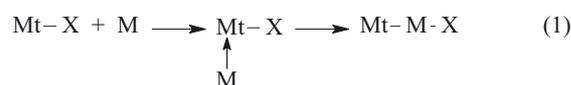
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Tin(II) 2-ethylhexanoate is commonly used as a commercial catalyst for the ring opening polymerization of cyclic esters and carbonates, however, dozens of alternative catalysts based on organic derivatives of other metals have been described in the patents and in open literature [14—16]. Aluminum alkoxides, dialkylaluminum alkoxides, zinc alkoxides, alumoxanes and bimetallic μ-oxoalkoxides are the most representative and widely used compounds [17—21]. The biodegradable linear aliphatic polyesters and polycarbonates can be also obtained *via* alternating copolymerization of oxiranes with cyclic anhydrides [eq. (2)] or carbon dioxide [eq. (3)].

$$(2)$$

$$(3)$$
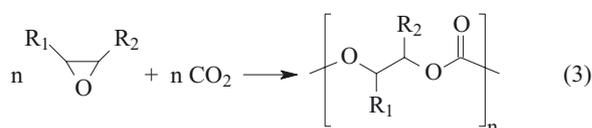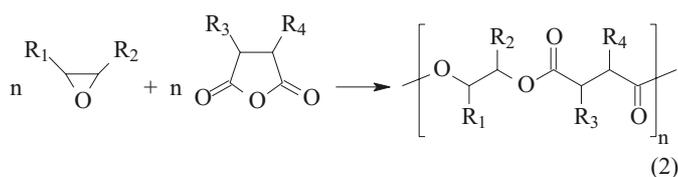
The latter reaction requires a coordination catalysts composed of a central metal (Zn, Al, Co, Cr) and organic chelating ligands like phenols, alkoxides, carboxylates, salens, porphyrins or β-diiminates [22, 23]. This type of catalyst allows also to perform the terpolymerization of carbon dioxide, oxiranes and cyclic esters to produce new families of biodegradable materials [24].

The well known disadvantage of catalytic polymerization is the contamination of the final products by residual metals originating from the catalyst applied. Most of them are toxic for humans and their concentrations in a biodegradable polymers should be kept below a certain maximum permissible metal concentration which depends on the kind of metal and product application. For example, the maximum concentration of residual tin in containers for human blood and blood components is 20 ppm, whereas the concentration of zinc which does not cumulate in living organisms, may be as high as 0.2 % [25]. Therefore, the zinc based catalysts can be regarded as potential candidates for the preparation of biodegradable materials of low toxicity.

One of the goal of this work was to determine the content of residual Zn in several materials which were prepared in the presence of very active coordination catalysts developed earlier in our laboratory [16, 24, 26]. We have also determined the contents of Al, Sn, and Cr (which are regarded as a highly toxic residues) in prepared by us and some commercially available biodegradable polymers to have some general idea about the levels of metallic contamination in these products and report on the reliable analytical methods which should be included to the traditional set of tools applied in laboratories working on the new "green polymers" and new catalytic systems for ring opening polymerization.

EXPERIMENTAL

Materials

Substances used in polymer syntheses

All materials were purified, stored and used in dry nitrogen atmosphere. Toluene (POCh), benzene (POCh) and 1,4-dioxane (POCh) were fractionally distilled from sodium/potassium and benzophenone after color change to navy blue, and then stored over dried 4 Å molecular sieves. Propylene oxide (POX, Merck) was dried over CaH_2, then fractionally distilled onto dried 5 Å molecular sieves; stored at 4 °C under nitrogen. Ethylene carbonate (EC, Aldrich) was dried over P_4O_{10}, then fractionally distilled under reduced pressure and crystallized from dry methylene chloride. Methylene chloride (POCh) for the latter purpose was fractionally distilled from CaH_2 onto dried 4 Å molecular sieves. Carbon dioxide (pure, Multax S.C.) was used as supplied. (3*S*)-*cis*-3,6-dimethyl-1,4-dioxane-2,5-dione (L-lactide, L-LA, Aldrich) was crystallized from dry 2-propanol, then from toluene and finally dried at 30 °C under vacuum; it was stored at 4 °C under nitrogen. 2-Propanol (POCh) was dried over CaH_2 and then fractionally distilled. Ethanol (POCh) and 1-butanol (POCh) were fractionally distilled from Mg/I_2 and stored over 4 Å molecular sieves. Polyoxyethylene glycol monomethyl ether (PEO, molecular weight 350, Fluka) was conditioned under reduced pressure at 70 °C for several hours and then stored in dry nitrogen. Pyrogallol (PgI, 1,2,3--trihydroxybenzene, Aldrich) was crystallized from ethanol/benzene (1:1), dried under vacuum and stored under nitrogen. Tin(II) 2-ethylhexanoate [$Sn(Oct)_2$, Aldrich], diethylzinc ($ZnEt_2$, Aldrich) and methylalumoxane (MAO, 10 wt. % in toluene, Aldrich) were used as supplied. Methylene chloride (POCh, pure) and methanol (POCh, pure) for purification of crude polymers were used as supplied.

Commercial polymers

Commercial NatureWorks® polylactide (PLA, Cargill-Dow) and poly(propylene carbonate) (PPC) (supplier for authors' knowledge only) were used as supplied as well as after further purification comprised of dissolution in methylene chloride and shaking once with diluted hydrochloric acid, three times with distilled water and dropping the organic phase into stirred methanol to precipitate the polymer which then was dried under vacuum at 50 °C for 2 days.

Dexon® (polyglycolide) and Vicryl® (copolymer glycolide/L-lactide) sutures (Ethicon) were used as supplied.

Compounds used in analytical procedures

The following reagents were used in analytical procedures: nitric(V) acid (JT Baker), concentrated (65 % w/w) and diluted (1 + 4 v/v), ammonium dihydrogen

phosphate(V) (Merck), magnesium matrix modifier (Merck), stock standard solutions for aluminum, beryllium, chromium, tin and zinc (1mg/ml) (JT Baker or Merck). Working solutions were prepared for each element in nitric acid (1 + 4) with water and deionised up to the resistivity of 18 MΩ in Milli-Q System (Millipore, USA).

Catalytic systems syntheses

The preparation of zinc alkoxide [EtZnO(CH$_2$CH$_2$O)$_{7.2}$CH$_3$ — ZnPEO] was carried out in 50 ml three-neck round-bottom flasks equipped with a magnetic stirrer, addition funnel, dry-ice condenser coupled with a gas burette and nitrogen adapter replaceable with stopper. Dry-ice/acetone bath was used as a cooling medium. Equimolar quantities of ZnEt$_2$ (2 M in 1,4-dioxane, 10 mmol, 5.0 ml) and PEO (1 M in 1,4-dioxane, 10 mmol, 10.0 ml) were used and the reaction was carried out at 10—15 °C until PEO solution was added dropwise to ZnEt$_2$ solution.

ZnEt$_2$/pyrogallol (ZnPg) was obtained similarly to zinc alkoxide, however, the ratio of ZnEt$_2$ (2 M in 1,4-dioxane, 12 mmol, 6 ml) and pyrogallol (0.5 M in 1,4-dioxane, 4 mmol, 8 ml) was 3:1.

The reaction of Sn(Oct)$_2$ with butanol (SnBu, which is an equilibrium one) took place *in situ* in further reaction systems of the polymerization reaction with EC.

Polymers syntheses

The polymerizations of L-LA and its copolymerizations with EC or POX were carried out in glass pressure ampoules sealed by a screw with gasket on coupling, in dry nitrogen atmosphere. An appropriate mixture of solutions of L-LA (3.5 M in 1,4-dioxane, *e.g.* 20 mmol, 5.7 ml) and EC (3.0 M in 1,4-dioxane or toluene, *e.g.* 20 mmol, 6.7 ml) or liquid POX (*e.g.* 20 mmol, 1.4 ml) were placed in polymerization ampoules using glass syringes. Then, the solution of a respective catalytic system in 1,4-dioxane or toluene (0.4 mmol of metal species, usually 0.5 ml of 0.8 M solution) was added by a glass syringe. When all the components were added, the ampoule was placed in an oil bath at appropriate temperature (*e.g.* 120 °C). After a desired time (usually 48 h) the ampoule was cooled, degassed, opened and methylene chloride was added in order to dissolve the reactants. The organic solution was shaken once with diluted hydrochloric acid to wash out the catalyst residue. Then, the organic phase was washed with distilled water three times and dropped into stirred methanol to precipitate the polymer. The products were dried under vacuum at 50 °C for 2 days.

The copolymerizations of POX with CO$_2$ and terpolymerization with CO$_2$ and L-LA were carried out in a steel autoclave in dry nitrogen atmosphere. An appropriate mixture of liquid POX (*e.g.* 20 mmol, 1.4 ml) and

solution of L-LA (3.5 M in 1,4-dioxane, *e.g.* 20 mmol, 5.7 ml) were placed in the polymerization autoclave using glass syringes. The solution of a respective catalytic system in 1,4-dioxane or toluene (0.4 mmol of metal species, usually 0.5 ml of 0.8 M solution) was added by a glass syringe. When all liquids and dissolved components were added, the autoclave was joined to a carbon dioxide cylinder using copper capillary and then both valves: at the gas bottle and autoclave were opened for 10 minutes. After that time a 10—20 fold excess of CO$_2$ with respect to POX was loaded to the autoclave so the valves were closed and the capillary was disconnected. The reactor was placed in an oil bath at appropriate temperature (usually 35—80 °C). After a desired time (usually 48 h) the autoclave was cooled, degassed, opened and further procedure was identical as in the case described before process in ampoule.

Methods of testing

Sample preparation

0.1—0.25 g of polymer sample weighted with accuracy up to 0.5 mg was placed in a PTFE vessel. Then 2 ml of concentrated nitric acid were added and digestion procedure was realized during mineralization program (Table 1) which was followed by cooling in air flow (Multiwave 3000 system, Anton Parr, Austria). Then the samples were quantitively transferred to polyethylene volumetric tubes and diluted up to 10 ml with deionized water. Blank tests were prepared by the same digestion procedures.

T a b l e 1. Mineralization program

Step	Initial power, W	End power, W	Ramp time, min
1	100	300	5
2	0	0	1
3	300	600	5
4	0	0	1
5	600	800	5
6	0	0	1
7	800	1000	5
8	0	0	1
9	1000	1000	10
10	0	0	15 (cooling)

Zn determination by FAAS

Zinc was determined by flame atomic absorption spectrometry (FAAS) using a Solaar 989 spectrometer (Unicam, Great Britain), in air-acetylene flame (Table 2). Background absorption during zinc determinations was corrected by a deuterium lamp.

Cr and Sn determinations by ETAAS

Chromium and tin were determined by electrothermal atomic absorption spectrometry (ETAAS) using an Avanta Ultra Z spectrometer (GBC, Australia) equipped

with electrothermal atomizer and PAL4000 autosampler (Table 3). Background correction was performed using the longitudinal Zeeman's effect measuring ETAAS signals in peak height mode. Temperature programme of graphite oven is shown in Table 4.

T a b l e 2. Operating conditions for zinc determination by FAAS method

Parameter	Value
Wavelength, nm	213.9
Slit, nm	0.5
Lamp current, mA	10.0
Background correction	deuterium
Fuel	acetylene
Oxidant	air
Flame	stoichiometric
working range, mg/l	≤ 2

T a b l e 3. Operating conditions for chromium and tin determination by ETAAS method

Parameter	Value for	
	chromium	tin
Wavelength, nm	357.9	235.5
Slit, nm	0.2	0.5
Lamp current, mA	6.0	5.0
Background correction	Zeeman's effect	Zeeman's effect
Magnetic field, T	0.75	1.0
Working range, ng/l	≤ 10	≤ 100
Sample volume, μl	10	10
Matrix modifier	1 % $NH_4H_2PO_4$ + 0.06 % $Mg(NO_3)_2$	0.3 % $Mg(NO_3)_2$
Modifier volume, μl	5	5

T a b l e 4. Temperature program

Tempera-ture, °C	Ramp time, s	Hold time, s	Inert gas	Auxiliary gas
50	1.0	1.0	off	on
Sample and modifier				
90	15.0	10.0	off	on
120	10.0	15.0	off	on
120	0.0	5.0	off	on
1000	10.0	5.0	on	off
1000	0.0	1.0	off	off
2600	0.6	0.4	off	off
2700	0.2	0.8	on	off

Al determination by ICP-OES

Aluminum was determined by inductively coupled plasma optical emission spectrometry (ICP-OES) using an Optima 3100XL spectrometer (Perkin Elmer).

Polymer samples were mineralized according to the following procedure developed at the Central Forensic Laboratory of the Police in Warsaw. Approximately 250 mg of the polymer sample was placed in a teflon vessel and then 3 ml of 65 % nitric acid (Suprapur®, Merck, Germany) and 1 ml of 30 % hydrogen peroxide (Suprapur®, Merck, Germany) were added. The vessel was placed in the microwave system (MULTIWAVE, Anton Paar, Perkin Elmer) and mineralized (see Table 1). After decomposition, the sample was transferred into a 10 ml volumetric flask (class A, Brand®) and filled up to volume with double distilled water. The introduction of samples was ensured by a concentric nebulizer (Meinhard c) and a glass spray chamber. Determinations of Al were made at the wavelengths 394.401 and 308.215 nm. The operating conditions of the ICP-OES spectrometer are shown in Table 5.

T a b l e 5. Operating conditions of the ICP-OES spectrometer

Parameter	Value
Generator power RF, kW	1.45
Plasma Ar flow, l/min	15.0
Auxiliary Ar flow, l/min	0.5
Nebuliser Ar flow, l/min	0.5
Sample uptake, ml/min	0.65
Correction points for Al	$Al_{394,401}$ -0.028; + 0.028 $Al_{308,215}$ -0.036; + 0.036

Calibration

Calibration was performed by using single element calibration solutions (5 % HNO_3) prepared from $1\ g \cdot l^{-1}$ stock solution (Suprapur®, Merck, Germany). The internal standards solutions of Y and Be, containing 2 and $1\ mg \cdot l^{-1}$ of the elements were mixed with blanks, samples and standards online, respectively.

RESULTS AND DISCUSSION

The list of the analyzed polymers the determination (by atomic spectrometry) and the results of our investigations of the contents of metals in them by three described above variants of the atomic spectrometric methods are collected in Table 6.

Zinc was used in the molar ratio of 1:50 with respect to the monomers in the polymerization mixture and removed by washing the polymers solutions. The concentrations of residual zinc in most of the final products were in the range of 2—45 ppm, which was 50—1000 times lower than the maximum content accepted for materials used in biomedical applications [25]. The significantly higher concentration of Zn (but still below the limit accepted) were found for the high molecular weight PPC (run 2) or carbonate rich lactide based block terpolymer (run 9), obtained in the presence of $ZnEt_2$/Pg systems. The reason is that the efficacy of the interfacial metal extraction from CH_2Cl_2 solution is probably dependent on the solution viscosity and, in turn, on the polymer molecular weight. Generally, the standard deviations are low within a sample run, however, in the systems of low concentration of zinc (runs 1,

T a b l e 6. Metals contents in polymers

Run	Analyzed polymer[a]	Catalytic system[b]	Metals contents, ppm			
			Al[c]	Cr[d]	Sn[e]	Zn[f]
1	PPC (alternating copolymer synthesized from POX and CO_2, M_n = 90 900)	ZnPg	<MDL	0.2 ± 0.1	0.4 ± 0.1	11.7 ± 0.7
2	PPC (alternating copolymer synthesized from POX and CO_2, M_n = 2 010 000)	ZnPg	<MDL	0.4 ± 0.1	1.2 ± 0.2	1850 ± 24
3	Commercial PPC (M_n = 103 000) as supplied, washed with HCl_{aq} and water	ND	<MDL	3.0 ± 0.2	5.7 ± 0.3	7944 ± 637
				1.0 ± 0.1		12.0 ± 0.7
4	PLA (homopolymer, M_n = 17 400)	ZnPg	<MDL	<MDL		43.2 ± 0.8
5	PLA (homopolymer, M_n = 11 200)	ZnPg	<MDL	<MDL	<MDL	4.5 ± 0.8
6	PLA (homopolymer, M_n = 30 000)	MAO	103 ± 3	0.3 ± 0.1		
7	PLA (homopolymer, M_n = 48 000)	Sn	<MDL	<MDL	1.1 ± 0.1	<MDL
8	Commercial NatureWorks® PLA (M_n = 180 000) as supplied, washed with HCl_{aq} and water	ND	—	<MDL	7.5 ± 0.4	<MDL
				<MDL	7.9 ± 0.4	10.0 ± 0.5
9	Terpolymer consisting of LA (65 wt. %), PC (33 wt. %) and POX (2 wt. %) in m.u., bimodal of $M_{n,1}$ = 22 100 and $M_{n,2}$ = 2 090 000	ZnPg	<MDL	0.7 ± 0.1	3.3 ± 0.3	204 ± 3
10	Terpolymer consisting of LA (95 wt. %) and PC (5 wt. %) in m.u., M_n = 13 800	ZnPEO		0.8 ± 0.1	1.6 ± 0.2	27.7 ± 0.5
11	Copolymer consisting of LA (95 wt. %) and EC (5 wt. %) in m.u., M_n = 19 600	ZnPg			0.3 ± 0.1	6.0 ± 0.2
12	Copolymer consisting of LA (96 wt. %) and EC (4 wt. %) in m.u., M_n = 14 100	SnBu	<MDL	<MDL	10.0 ± 0.5	<MDL
13	Copolymer consisting of LA (76 wt. %) and POX (24 wt. %) in m.u., M_n = 16 500	MAO	2827 ± 113	0.2 ± 0.1		
14	Commercial Dexon®	ND	MDL	2.7 ± 0.2	2.2 ± 0.1	7.8 ± 0.2
15	Commercial Vicryl®	ND	15 ± 1	3.3 ± 0.3	13.5 ± 0.6	16.1 ± 0.8

[a] PPC — poly(propylene carbonate), PLA — polylactide; m.u. — monomer unit in mol %, LA — lactide, EC — ethylene carbonate, POX — propylene oxide, PC — propylene carbonate.
[b] Sn — Tin(II) 2-ethylhexanoate, SnBu — Tin(II) 2-ethylhexanoate/n-butanol (1:1), ZnPg — $ZnEt_2$/pyrogallol (3:1), ZnPEO — $ZnEt_2$/$HO(CH_2CH_2O)_{7.2}CH_3$ (1:1), MAO — methylalumoxane, ND — no data (commercial).
[c] Determination by FASS, MDL (Method Detection Limit) = 12 ppm.
[d] Determination by ETASS, MDL = 0.2 ppm.
[e] Determination by ETASS.
[f] Determination by ICP-OES, MDL = 3 ppm.

4) the deviations not shown in the Table 6 among different samples of the same polymer may be significant due to the non-homogeneous distribution of the metal. The traces of Cr (<1 ppm) and Sn (0.3—1.6 ppm) have been also detected in majority of the samples, whereas the concentration of aluminum was below the detection limit.

We also examined the sample of the commercial PPC alternating copolymer of M_n 103 000 (run 3) comprising of POX and CO_2 monomeric units. We found that the purity of this product is not sufficient for biomedical applications since the concentration of zinc ~0.8 % and Cr ~3 ppm are higher than the limits allowed (0.2 % and 1 ppm, respectively) [25]. The purification of this product using the procedure described in the experimental part allows, however, to obtain a product presenting accepted level of metallic contamination.

In order to compare the purity of products obtained in the presence of different metallic centres we have prepared the samples of poly(L-lactide) and copolymer of L-lactide with small amount of ethylene carbonate using tin based catalysts (runs 7 and 12) and poly(L-lactide) and L-lactide copolymer with propylene oxide using methylalumoxane (MAO) as catalyst (runs 6 and 13). As can be seen from Table 6, generally in the case of tin catalyst the standard method of purification leads to the reduction of tin content to the level of 1—10 ppm, whereas the concentration of Cr, Zn and Al is close to or below the detection limit. The analyses of commercially produced Nature Works® polylactide gave very similar results and additional purification had no effect on tin concentration (7—8 ppm).

We have examined also the samples of commercial products based on polyglycolide (Dexon®, run 14) and copolymer of glycolide (90 %) with L-lactide (10 %) (Vicryl®, run 15). These polymers used as surgery sutures are supposed to be prepared in the presence of tin based catalysts. It appeared, however, that the concentrations of tin in these products (2—14 ppm) were similar to those of zinc and aluminum what might suggest the use of more complex catalytic systems. Surprisingly these samples are also contaminated by ~3 ppm of chromium,

which exceeds the limit suggested in Pharmacopoeia for some biomedical application.

The samples prepared in the presence of MAO (runs 6 and 13) contain relatively high concentrations of aluminum (~0.3 % and ~ 100 ppm).

From the comparison of analytical data for various samples of polylactides (runs 4—7 and 13) one can conclude that removal of residual aluminum used as catalyst from the polymer of similar structure (PLA) is much more difficult than in cases of tin or zinc. This is probably one of the main reasons that aluminum based catalysts are not so far used in the production of biodegradable polymers. We cannot compare these data to standards of the corresponding materials used in medicine, because the respective standards are missing. The only existing standards are those for extractable Al quantities in polyolefins (not more than 1 ppm) [25]. However, looking at Al content of 12—15 ppm in the commercial sutures (Dexon® and Vicryl®), one can expect that this level of contamination is acceptable for biomedical applications.

CONCLUSIONS

Most of the analyzed polymers, synthesized in our laboratory in the presence of Zn or Sn based catalysts, contain residual metals at the level below pharmacopoeial standards for materials of blood containers. The results for those polymers synthesized by us are consistent with the results obtained for commercial polymers used for food packaging and for medical purposes (*e.g.* surgical bioresorbable sutures). There are only a few exceptions of polycarbonates and their copolymers of relatively high molecular weights, which were obtained with CO_2 use in the presence of Zn based catalysts and contained high levels of this metal (0.2—0.8 %). They require additional purification to be used as biomaterials.

Polymeric materials synthesized in the presence of Al catalysts seem to be not appropriate for biomedical purposes, because of too high Al concentrations.

Our work shows good performance of the applied analytical methods (EFAAS, ETAAS and ICP-OES) in respect to the biodegradable polymers' investigations, as far as selectivity, linearity and accuracy are concerned. The proposed analytical methodologies can be applied to routine monitoring of metals contents (Al, Zn, Sn and Cr) in biomedical polymers.

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