Copolyethersulfones of 1,4:3,6-dianhydrohexitols and bisphenol A

Chaouki Belgacem, Raouf Medimagh, Hans Kricheldorf, Hatem Ben Romdhane, and Saber Chattid

Abstract
The synthesis of biosourced copolyethersulfones by polycondensation of 1,4:3,6-dianhydrohexitol monomers and bisphenol A is reported. Structures and properties of these copolymers were investigated in each case. In the first part, the impact of the position of the two hydroxyl groups of isosorbide, isomannide, and isoidide is discussed. In the second part, we focused on improving the cost/thermal properties balance by introducing controlled proportions of bisphenol A as comonomer. The addition of bisphenol A serves two purposes. The first one is to maintain good thermal and mechanical properties of resulting copolymers. The second reason is to insure low-cost route to copolyethersulfones for a potential use in industrial applications. All the products have been fully characterized by NMR spectroscopy, MALDI-TOF spectrometry, and viscosimetry. The thermal properties were studied by differential scanning calorimetry (DSC).

Introduction
Nowadays, a particular and growing attention has been given to the use of natural resources in the production of non-food products.[1–3] This is of increasing interest not only because it is associated with the abundance of these sustainable resources, but also because it gives the possibility to substitute petroleum-based products with environment-friendly chemicals.[4,5] In this respect, many studies in the last decade have been devoted to the development and synthesis of biosourced materials such as polymers and copolymers deriving from natural products.[6]

The aim of this work was the elaboration of a novel copolyethersulfones starting from biosourced diols from corn starch in a simple and efficient step growth polymerization. These promising diols are 1,4:3,6-dianhydro-D-glucitol (isosorbide) (Figure 1(a)), 1,4:3,6-dianhydro-D-mannitol (isomannide) (Figure 1(b)) and 1,4:3,6-dianhydro-D-iditol (isoidide) (Figure 1(c)). These derivatives belong to the family of 1,4:3,6-dianhydrohexitols (DAHs) known for their interesting chirality and rigidity properties. Furthermore, these monomers display different levels of reactivity because of the stereochemistry of their hydroxyl groups. As shown in Figure 1, isosorbide (IS) has one exo and one endo hydroxyl group, isomannide (IM) has two endo hydroxyl groups, whereas for isoidide (Id), they are both in exo positions.[7] These properties seem to improve the quality and properties of the final products.

Recently, several studies described the use of dianhydrohexitol diols as building blocks for numerous oligomers, homopolymers, and copolymers.[8–11] Moreover, the synthesis of co-polyesters based on isosorbide and isomannide[12–14] and the polycondensation of co-polycarbonates of isosorbide have been reported.[15,16] However, to the best of our knowledge, no study has investigated the use of combinations of these diols to produce copolyethersulfones.

In this regard, this study describes the synthesis of novel copolyethersulfones (CoPES) by polycondensation of several combinations and various ratios of dianhydrohexitol units. Based on the known properties of these monomers, the final products are expected to exhibit good mechanical and thermal properties. As a second step and in order to improve further the properties of CoPES and maintain, at the same time, a reasonable production costs, we investigated the impact of introducing controlled ratios of bisphenol A (BPA) as comonomer. To achieve this objective, a series of reactions were conducted with various molar ratios and different combinations of DAHs and BPA. The structures and properties of resulting copolymers were characterized by $^1$H NMR spectroscopy and MALDI-TOF mass spectrometry techniques. The effects on the glass
methanol. The resulting precipitate is isolated by filtration, washed with cold methanol, and then dried in vacuo.

**Measurements**

The inherent viscosity ($\eta$) was measured with a Ubbelohde viscometer at 20 °C in CH$_2$Cl$_2$/TFA (9/1).

The 500 MHz NMR spectra were recorded on a Bruker “UltraShield Plus 500” spectrometer in 5 mm i.d. sample glass tubes. DMSO-D$_6$ containing 2 vol% of TFA served as solvent.

MALDI-TOF experiments were performed on an UltraflexIII (BrukerDaltonics) mass spectrometer including a time-of-flight analyzer. This instrument was equipped with a smart beam laser and was operated in reflectron mode and positive ionization mode. All data were reprocessed using the Flex Analysis software from Bruker Daltonics®. The target solutions were prepared in DMSO/TF-A solution at 2 g L$^{-1}$ with dithranol as a matrix and NaI as dopant. The calculated masses of the products discussed below are listed in Table 1.

Differential scanning calorimetric (DSC) data were obtained using a DSC-Q20, TA Instruments, USA in flowing argon (50 mL min$^{-1}$) at heating rate of 10 °C min$^{-1}$ from −50 to 320 °C.

**Representative NMR data**

Representative NMR data of protons related to structures of synthesized copolyethersulfones as represented in Figure 3 and Table 2 are detailed as follows:

| CoPES-1 | $^1$H NMR (DMSO-D$_6$, δ): 7.89–7.87 (d, 2H, H$_g$), 7.84–7.83 (d, 2H, H$_g$), 7.21–7.19 (d, 2H, H$_h$), 7.13–7.11 (d, 2H, H$_h$), 7.13–7.11 (d, 2H, |

---

**Table 1.** Masses (including Na + doping) of cyclic copolyethersulfones detected in the MALDI-TOF mass spectrum.

| Number of diol unit | Number of BPA units |
|---------------------|----------------------|
| 0                   | 0                    |
| 1                   | 1                    |
| 2                   | 2                    |
| 3                   | 3                    |
| 4                   | 4                    |
| 5                   | 5                    |
| 6                   | 6                    |
| 7                   | 7                    |
| 8                   | 8                    |
| 9                   | 9                    |

| Number of diol unit | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---------------------|---|---|---|---|---|---|---|---|---|---|
| 0                   | 908| 1350| 1793| 2235| 2678| 3120| 3563| 4005 |
| 1                   | 826| 1268| 1711| 2153| 2596| 3038| 3480| 3923 |
| 2                   | 744| 1186| 1629| 2071| 2514| 2956| 3399| 3841 |
| 3                   | 1104| 1547| 1989| 2432| 2874| 3317| 3759| 4202 |
| 4                   | 1464| 1907| 2349| 2792| 3234| 3677| 4119| 4562 |
| 5                   | 1825| 2267| 2710| 3152| 3595| 4037| 4480| 4922 |
| 6                   | 2185| 2628| 3070| 3513| 3955| 4398| 4840| 5283 |
| 7                   | 2545| 2988| 3431| 3873| 4316| 4758| 5200| 5643 |
| 8                   | 2906| 3348| 3791| 4233| 4676| 5118| 5561| 6003 |
| 9                   | 3266| 3709| 4151| 4594| 5036| 5479| 5921| 6364 |

---

**Table 2.** Copolyethersulfones of isosorbide, isomannide, and isoidide.

| Exp N° | Monomers | Feed ratio | Yields (%) | $\eta_{inh}$ (dL/g)$^a$ | $T_g$ (°C)$^b$ |
|--------|----------|------------|------------|-------------------------|----------------|
| CoPES-1 | IS/Im    | 5/5        | 97         | 0.31                    | 176            |
| CoPES-2 | Im/id    | 5/5        | 82         | 0.36                    | 169            |
| CoPES-3 | IS/id    | 5/5        | 98         | 0.45                    | 173            |

$^a$Measured at 20 °C with $c = 2$ g L$^{-1}$ in CH$_2$Cl$_2$/TFA (9/1).

$^b$Measured with a heating rate of 10 °C min$^{-1}$ under argon flow of (50 mL min$^{-1}$).
H\textsubscript{h}, 5.00 (brs, 3H, H\textsubscript{e} and H\textsubscript{g} and H\textsubscript{d}), 4.98 (m, 2H, H\textsubscript{a} and H\textsubscript{f}), 4.88 (s, H\textsubscript{c} and H\textsubscript{b} and H\textsubscript{e}), 4.53 (s, 1H, H\textsubscript{f}), 3.94–3.92 (m, 2H, H\textsubscript{a} and H\textsubscript{f}), 3.90 (m, 1H, H\textsubscript{g}), 3.77–3.74 (m, 1H, H\textsubscript{d}).

CoPES-2: $^1$H NMR (DMSO-D\textsubscript{6}, $\delta$): 7.88–7.86 (d, 2H, H\textsubscript{h}), 7.85–7.83 (d, 2H, H\textsubscript{h}), 7.21–7.19 (d, dH, H\textsubscript{g}), 7.14–7.12 (d, 2H, H\textsubscript{g}), 5.03 (s, H\textsubscript{c} and H\textsubscript{b}), 4.98 (s, 2H, H\textsubscript{c} and H\textsubscript{b}), 4.88 (s, 2H, H\textsubscript{c} and H\textsubscript{b}), 4.67 (s, 2H, H\textsubscript{c} and H\textsubscript{b}), 4.09–4.07 (m, 2H, H\textsubscript{a} and H\textsubscript{f}), 3.96–3.93 (m, 1H, H\textsubscript{g}), 3.77–3.74 (m, 1H, H\textsubscript{d}).

CoPES-3: $^1$H NMR (DMSO-D\textsubscript{6}, $\delta$): 7.86–7.85 (d, 2H, H\textsubscript{h}), 7.83–7.81 (m, 2H, H\textsubscript{h}), 7.18–7.16 (d, 2H, H\textsubscript{g}), 7.13–7.11 (d, 2H, H\textsubscript{g}), 5.02 (s, 2H, H\textsubscript{c} and H\textsubscript{b}), 5.01 (s, 3H, H\textsubscript{c} and H\textsubscript{b} and H\textsubscript{e}), 4.65 (s, 2H, H\textsubscript{c} and H\textsubscript{b}), 4.53 (s, 1H, H\textsubscript{f}), 4.07–4.06 (d, 2H, H\textsubscript{a} and H\textsubscript{f}), 3.93–3.91 (d, 2H, H\textsubscript{a} and H\textsubscript{d}).

CoPES-4: $^1$H NMR (DMSO-D\textsubscript{6}, $\delta$): 7.87–7.84 (d, 4H, H\textsubscript{h}), 7.30–7.27 (d, 4H, H\textsubscript{g}), 7.05–7.02 (d, 4H, H\textsubscript{g}), 6.99–6.96 (d, 4H, H\textsubscript{g}), 1.71 (s, 6H, H\textsubscript{k}).

CoPES-6: $^1$H NMR (DMSO-D\textsubscript{6}, $\delta$): 7.89–7.81 (m, 4H, H\textsubscript{h}), 7.28–7.26 (d, 4H, H\textsubscript{g}), 7.17–7.01 (m, 4H, H\textsubscript{g} and H\textsubscript{e}), 5.00 (brs, 3H, H\textsubscript{c} and H\textsubscript{b} and H\textsubscript{e}), 4.52 (s, 1H, H\textsubscript{f}), 3.94–3.88 (m, 2H, H\textsubscript{a} and H\textsubscript{d}), 1.71 (s, 6H, H\textsubscript{k}).

CoPES-8: $^1$H NMR (DMSO-D\textsubscript{6}, $\delta$): 7.87–7.81 (m, 4H, H\textsubscript{h}), 7.18–7.19 (d, 4H, H\textsubscript{g}), 5.00 (brs, 3H, H\textsubscript{c} and H\textsubscript{b} and H\textsubscript{e}), 4.52 (s, 1H, H\textsubscript{f}), 3.94–3.86 (m, 2H, H\textsubscript{a} and H\textsubscript{d}).

**Results and discussion**

**Copolycondensation of various diols with Bis (4-fluorophenyl)sulfone**

The use of dianhydrohexitols to produce copolymers was reported previously in a study conducted in 2007.[17] The study focused on the synthesis of copolycarbonates based on isosorbide and isomannide by means of diphosgene in

![Figure 2. Synthesis of copolyethersulfone of isosorbide, isomannide, and isoidide.](image)

![Figure 3. $^1$H NMR spectra of homo-PES of IS (a), Copolymers: (b) IS/Im, (c) IS/Id, (d) Id/Im [3.5–8.5 ppm] [DMSO-D6, 500 MHz, 20 °C].](image)
dioxan. It was reported that the resulting copolymers had a relatively good glass transition temperatures up to 163 °C and were characterized by high molar fraction of cycles. Nevertheless, isoidide was not investigated in these experiments. In this work, we aim to extend the use of those biosourced isomers to produce aromatic copolyethersulfones. Copolymers were prepared starting from a mixture of two dianhydrohexitols and Bis(4-fluorophenyl)sulfone according to CoPES-1, CoPES-2, and CoPES-3 in Figure 2 and Table 2. The experimental conditions were chosen as described previously by Chatti et al. [18] as to yield cyclic polyethersulfones.

Viscosity measurements were used as an indicator of the degree of progress of polycondensation and thus the chain growth. The products, obtained at equimolar stoichiometry ratios, showed slight increase in inherent viscosity from 0.31 dg/L for CoPES-1 based on IS/Im to 0.45 dg/L for CoPES-3 of IS/Id. This observation might be owed to the difference of reactivity exhibited by each of the monomers because of the stereochemistry of their hydroxyl groups. Basically, the significantly low viscosity registered for CoPES-1 is owed to the fact that the hydroxyl groups of isomannide are engaged into intramolecular hydrogen interactions because of their endo positions inside the V shape of the molecule. These interactions reduce the diol reactivity and thus inhibit the reaction progress leading to shorter chains of copolymers. Yet, it is inferred that the relatively higher viscosity obtained for copolymers based on the couple IS/Id is associated to their slightly different stereochemistry compared to Im as described previously in this study. Furthermore, the presence of the exo substituent increases the stability of the cycle to which it is attached.[19] This observation agrees with the literature [3,20,21].

Further structural characterization by $^1$H NMR spectroscopy was conducted. The spectra of CoPES-1, CoPES-2, and CoPES-3 given, respectively, in Figure 3(b), (c), and (d) were compared to the spectrum of a cyclic homopolyethersulfone starting from IS given in Figure 3(a) and previously reported by Chatti et al. [18] The overlapping of these spectra allowed the identification of characteristic and specific signals of each isomer separately. Moreover, it demonstrates a dominance of signals related to repetitive blocks and the absence of signals related to the side chain groups. Interestingly, one can clearly see the effect of endo/exo positions when compared with the other two isomers.

Furthermore, MALDI-TOF spectra exhibited in Figure 4 demonstrate exclusively peaks of cyclic copolymers, indicating that the chain growth was mainly limited by cyclization and not by side reaction, stoichiometric imbalance, or incomplete conversion.

![Figure 4. MALDI-TOF spectra of Homo-PES of IS (a), copolymers: (b) IS/Im, (c) IS/Id, (d) Id/Im.](image-url)
Copolyethersulfones of dianhydrohexitols and bisphenol A

Due to the relatively high costs of 1,4:3,6-dianhydrohexitols,[7,22] special attention was given, in this part, to maintain a low-cost route to copolyethersulfones and to improve their good thermal properties. To achieve this objective, we envisioned introducing controlled feed ratios of bisphenol A as comonomer (Figure 5).

Copolymers isolated from polycondensation of dianhydrohexitols and bisphenol A were investigated by 1H NMR spectroscopy. This technique was helpful to calculate the actual molar composition of monomers compared to the initial feed ratios. The molar compositions, mentioned in Table 3, state the proportions of dianhydrohexitol (IS, Im, or Id) and bisphenol monomers in the copolyethersulfones structure. The calculation of these ratios is based on the integration of experimental 1H NMR signals characterizing each of the two monomers which gives an idea about the structural composition, which agreed fully with the introduced feed ratios (Table 3).

Moreover, viscosity measurements gathered in Table 3 show that viscosities were affected by introducing appropriate ratios of DAHs. Homopolyethersulfone of bisphenol A has a viscosity equal to 0.43 dL/g. However, products based on isosorbide (CoPES-8) or isoidide/bisphenol A (CoPES-10) show higher inherent viscosity values equal to 0.65 and 0.51 dL/g. The increase in the viscosity values reflects the synthesis of copolymers with higher molecular weights when those biosourced monomers are involved. In fact, earlier studies have demonstrated that the reactivity of monomers impacts the progress of polycondensations, the chain growth, and the copolymers composition.[23,24] Furthermore, monomers with low reactivity may lead to a shorter chain of polymers and therefore displays low inherent viscosities. These findings agree with the results given in Table 3. Indeed, when we compare the viscosities for the same feed ratio of DAH/BPA, we note that isomannide displays a relatively low viscosity equal to 0.32 dL/g registered for CoPES-9. However, isoidide, which is the most reactive monomer among the dianhydrohexitols isomers, led to CoPES-10 with an inherent viscosity equal to 0.51 dL/g.

MALDI-TOF spectra displayed mainly series of intensive peaks with masses up to 5000 Da (Figure 6). Spectra profile of CoPES based on IS, Im, and Id showed a series of peak masses related to cyclic bisphenol A homopolymers together with peaks related to copolymers. The diol nature seemed not to induce a significant impact on the

![Figure 5. Copolyethersulfone of DAHs/ BPA; is/BPA: CoPES-5, 6, 8; im/BPA: CoPES-9; and id/BPA: CoPES-10.](image)

Table 3. Copolycondensation of IS (10 mmol) with either BPA (10 mmol) and DFDPs (10 mmol) + 2%) using the same reaction conditions as those of CoPES-8.

| Copol.  | Diol/BPA | Feed ratio | Yields (%) | T_g (°C)a | η_inh b(dL/g) | Molar composition/IS/BPA |
|--------|----------|------------|------------|-----------|--------------|--------------------------|
| CoPES-4 | BPA      | 0/10       | 95         | 196       | 0.43         | 0/10                     |
| CoPES-5 | IS/BPA   | 3/7        | 97         | 210       | 0.45         | 3.0/7.7                  |
| CoPES-6 | IS/BPA   | 5/5        | 95         | 219       | 0.34         | 5.0/5.2                  |
| CoPES-8 | IS/BPA   | 10/0       | 97         | 242       | 0.65         | 10.0/0.0                 |
| CoPES-9 | Im/BPA   | 5/5        | 96         | 217       | 0.32         | 5.0/5.7                  |
| CoPES-10| Id/BPA   | 5/5        | 98         | 228       | 0.51         | 5.0/5.5                  |

aMeasured with a heating rate of 10 °C min⁻¹ under argon flow of (50 mL min⁻¹).
bMeasured at 20 °C with c = 2 g L⁻¹ in CH2Cl2/TFA (9/1).
As determined by 1H NMR spectroscopy.
Figure 6. MALDI-TOF spectra of homopolyethersulfone of BPA (a), CoPES of IS/BPA (b), Im/BPA (c), Id/BPA (d).
CoPES-10 exhibit the characteristic signals of Im and Id, respectively, as mentioned previously in this study.

Thermal stability of reaction products was investigated by DSC analyses.

Homopolyethersulfones of bisphenol A shows rather lower \( T_g \) (196 °C). Furthermore, we observed that glass temperature decreases as the proportion of bisphenol A increases. In addition, thermal properties seem to be affected by the chemical reactivity of the dianhydrohexitols. Copolymer (CoPES-10) of bisphenol A and isoidide which is the most reactive isomer \([7,25]\) showed the highest \( T_g \) (228 °C). On the other hand, isomannide-based copolymer presented the lowest glass temperature (217 °C).

Because of the low cost of isosorbide and bisphenol A and because they are commercially available on an appreciable scale \([3,26,27]\) compared to isomannide and isoidide, CoPES-6 based on IS/BPA (1:1) would be a promising candidate for further industrial processing. This copolymer has shown high glass transition temperatures (219 °C), excellent thermal stability, and interesting physical properties (Figure 8).

**Conclusions**

Copolycondensation of dianhydrohexitols and bisphenol A with Bis(4-fluorophenyl)sulfone prepared according to the synthetic approach have yielded nearly random sequences of copolyethersulfones as evidenced by the various analytical techniques used. Furthermore, the MALDI-TOF mass spectra indicated the formation of a high molar fraction of cycles, suggesting that high conversions and reaction conditions almost free of side reactions destroying functional groups were achieved. Sufficiently high molecular weights and relatively high glass transition temperatures meant that such copolyethersulfones would be useful for high engineering applications. Nonetheless, all DSC measurements suggest that copolyethersulfones of dianhydrohexitols and bisphenol A may be used as transparent engineering materials with relatively high glass temperatures in the range of 210–228 °C.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**ORCID**

Chaouki Belgacem [http://orcid.org/0000-0002-8534-961X](http://orcid.org/0000-0002-8534-961X)

**References**

[1] Miriam F, Beristain MN, Kazukiyo N, et al. Synthesis and characterization of poly[propargyl(3-methoxy-4-propargyloxy)cinnamate]: a polymer from a natural product. Des. Monomers Polym., 2009;12:257–263.
[2] Makito Y, Masahiko O. Biodegradable polymers based on renewable resources. IX. synthesis and degradation behavior of polycarbonates based on 1,4:3,6-dianhydrohexitols and tartaric acid derivatives with pendant functional groups. J. Polym. Sci., Part A: Polym. Chem. 2005;43:11. Epub 3919.

[3] Noordover BAJ. Biobased step-growth polymers: chemistry, functionality and applicability. Dutch Polymer Institute Technische Universiteit North Brabant, Eindhoven; 2007.

[4] Chauhan NPS. Facile synthesis of environmental friendly halogen-free microporous terpolymer from renewable source with enhanced physical properties. Des. Monomers Polym. 2012;15:587–600.

[5] Shrawan K, Shukla AM, Srivastava D. Studies on the effect of concentration of formaldehyde on the synthesis of resole-type epoxidized phenolic resin from renewable resource material. Des. Monomers Polym. 2014;17:69–77.

[6] Pillai CKS. Challenges for natural monomers and polymers: novel design strategies and engineering to develop advanced polymers. Des. Monomers Polym. 2010;13:87–121.

[7] Fenouillot F, Rousseau A, Colomines G, et al. Polymers from renewable 1,4:3,6-dianhydrohexitols (isomannide and isoidide). Prog. Polym. Sci. 2010;35:578–622.

[8] Abderrazak Hana B, Fildier A, Romdhane HB, et al. Synthesis of new poly(etherketone)s derived from biobased diols. Macromol. Chem. Phys. 2013;214:1423–1433.

[9] Wolff E, Dariusz B, Loupy A, et al. Microwave-assisted synthesis of polymers containing 1,4:3,6-dianhydrohexitols. 9th Electronic Conference on synthesis Organic Chemistry ECSOC; Coruña, Spain; 2005.

[10] Ivan S, Ristic NV, Cakic S. Synthesis and characterisation of polyester based on isosorbide and butanedioc acid. J. Polym. Environ. 2012;20:519–527.

[11] Belgacem C, Raouf M, Fildier A, et al. Synthesis and characterization of isosorbide-based α, ω-dihydroxyethersulfone oligomers. Des. Monomers Polym. 2014;18:64–72.

[12] Chatti S, Steffen M, Weidner, Fildier A, et al. Copolymesters of isosorbide, succinic acid, and isophthalic acid: biodegradable, high Tg engineering plastics. J. Polym. Sci., Part A: Polym. Chem. 2013;51:2464–2471.

[13] Hans R, Kricheldorf SMW. High Tg copolymesters of lactide, isosorbide and isophthalic acid. Eur. Polymer J. 2013;49:2293–2302.

[14] Naves AF, Fernandes HTC, Immich APS, et al. Enzymatic syntheses of unsaturated polymers based on isosorbide and isomannide. J. Polym. Sci., Part A: Polym. Chem. 2013;51:3881–3891.

[15] Makito Y, Aoi K, Okada M. Biodegradable polymers based on renewable resources. VII. Novel random and alternating copolycarbonates from 1,4:3,6-dianhydrohexitols and aliphatic diols. J. Polym. Sci., Part A: Polym. Chem. 2003;41:2312–21.

[16] Chatti S, Hans R, Kricheldorf, Schwarz G. Copolycarbonates of isosorbide and various diols. J. Polym. Sci., Part A: Polym. Chem. 2006;44:3616–3628.

[17] Hani MA, Chatti S, Kricheldorf HR, et al. Polycondensation of isosorbide and various diols by means of diphosgene characterization by a combination of MALDI and NMR. Recent Res. Devel Organic Chem. 2007;11:1–11.

[18] Chatti S, Hani MA, Bornhorst K, et al. Poly(ether sulfone) of isosorbide, isomannide and isoidide. High Perform. Polymer. 2007;21:105–18.

[19] Varkey EC, Sreekumar K. Isosorbide based chiral polyurethanes: optical and thermal studies. J. Mater. Sci. 2010;45:1912–1920.

[20] Vazifehasl Z, Hemmati S, Zamanloo M, et al. Synthesis and characterization of novel diglycidyl methacrylate-based macromonomers on isosorbide for dental composites. Macromol. Res. 2013;21:427–434.

[21] Noordover BAJ, van Staalduinen VG, Duchateau R, et al. Co- and terpolyesters based on isosorbide and succinic acid for coating applications: synthesis and characterization. Biomacromolecules. 2006;7:3406–3416.

[22] Chatti S, Bortolussi M, Bogdal D, et al. Microwave-assisted polycondensation of aliphatic diols of isosorbide with aliphatic disulphonylenesters via phase-transfer catalysis. Eur. Polym. J. 2004;40:561–577.

[23] Thiruvasagam P. Synthesis and characterization of AB-type monomers and polyimides: a review. Des. Monomers Polym. 2013;16:197–221.

[24] Esen H. Synthesis and characterization of linear dendritic homo and copolymers acrylated behera amine. Des. Monomers Polym. 2005;18:745–752.

[25] Jeol S. Stratégies de modifications physico-chimiques des polyesters semi-cristallins. Application à la fabrication de bouteilles en poly (éthylène téréphtalate) [Matériaux Polymères et Composites]. de Lyon: INSA; 2006.

[26] Al KE. Macrocycles 27: cyclic aliphatic polyesters of isosorbide. J. Polym. Sci., Part A: Polym. Chem. 2003;41:3414–3424.