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ИНСТИТУТ ПО ПОЛИМЕРИ

СТРУКТУРНИ ФОНДОВЕ

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"Развитие на човешките ресурси"

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ПЪРВА ПОСТЕРНА СЕСИЯ: "МЛАДИТЕ УЧЕНИ В СВЕТА НА ПОЛИМЕРИТЕ"

04 юни 2009 г.

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Novel Polymer Materials Based on Polyelectrolyte Complexes between *N*-Carboxyethylchitosan and Poly[2-(Dimethylamino)Ethyl Methacrylate] with A Potential Biomedical Application

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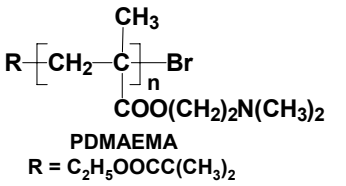
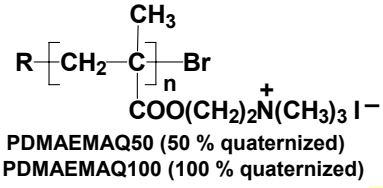
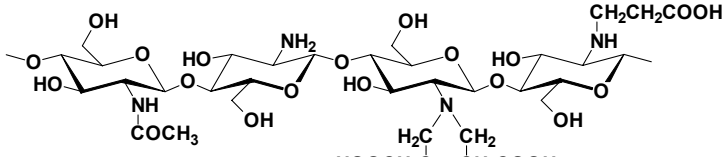
Aim: To prepare novel materials based on polyelectrolyte complexes (PECs) between the derivative of the natural polysaccharide chitosan (*N*-carboxyethylchitosan) and (quaternized) PDMAEMA, and to demonstrate some of their potential applications.



PDMAEMA
R = $C_2H_5OOCC(CH_3)_2$

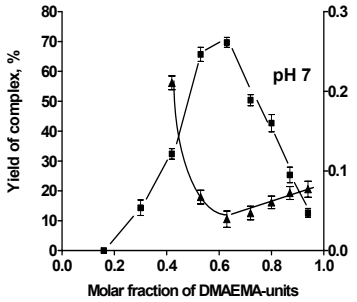


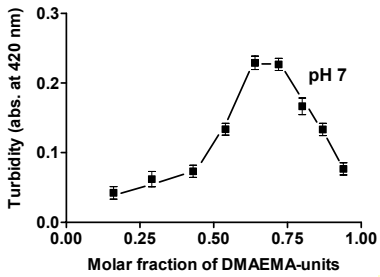
PDMAEMAQ50 (50 % quaternized)
PDMAEMAQ100 (100 % quaternized)



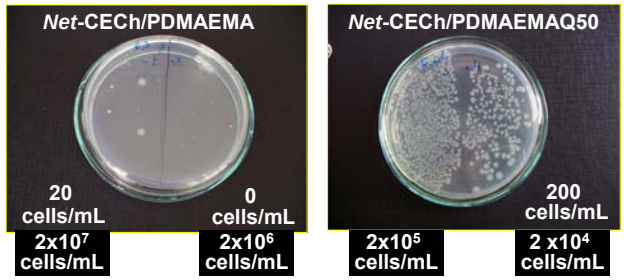
N-carboxyethylchitosan (CEChi)

Water-insoluble CEChi/PDMAEMA complex is formed in a narrow pH range around 7.

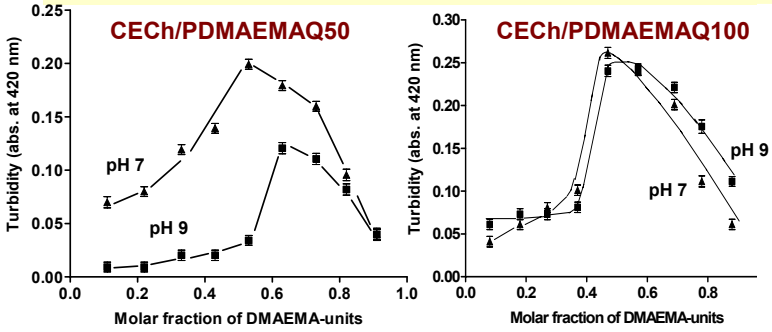




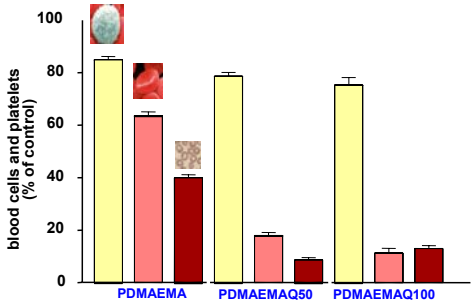
The PEC formation leads to a decrease of the inherent antibacterial activity of (quaternized) PDMAEMA. At pH<6 the complexes disintegrate and (quaternized) PDMAEMA exhibits its antibacterial activity.



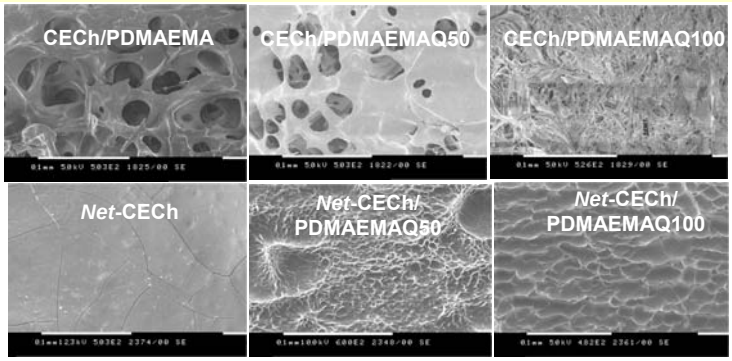
The partial or complete quaternization of the amino groups in the case of PDMAEMAQ50 and PDMAEMAQ100 allows PEC formation with CEChi both in neutral and alkaline medium.

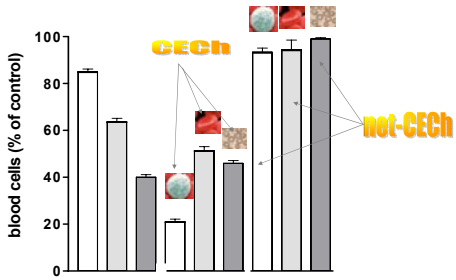


(Quaternized) PDMAEMA and CEChi decrease the red blood cell and platelet counts after 30-min incubation of polymer samples in whole blood. The crosslinking of CEChi improves its haemocompatibility.

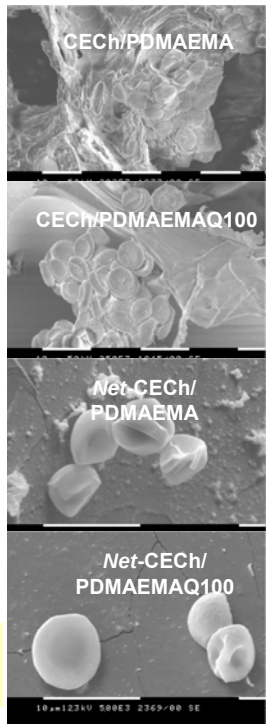


The structure of the obtained PECs depends strongly on the nature of the polycation and on the crosslinking of CEChi.





The complex formation reduces the toxicity of the polymer partners to the blood cells. Red blood cells with preserved morphology and no platelets are observed on the surface of the complexes by SEM.



Conclusion: Novel materials based on (*net*-)CEChi/(quaternized) PDMAEMA PECs have been prepared and their potential application as antibacterial and haemostatic agents has been demonstrated.

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Refs: [1] E. Yancheva, D. Paneva, V. Maximova, L. Mespouille, P. Dubois, N. Manolova, I. Rashkov, *Biomacromolecules* 8: 976-984, 2007.
[2] E. Yancheva, D. Paneva, D. Danchev, L. Mespouille, P. Dubois, N. Manolova, I. Rashkov, *Macromol. Biosci.* 7: 940-954, 2007.

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Stabilized Aggregates of Copolymers with a Hydrophobic Poly(styrene-r-diene) and a Hydrophilic Poly(glycidol) blocks

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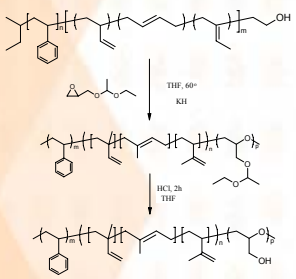
Goal

Stabilized micelles/aggregates formed from amphiphilic copolymers with a hydrofobic poly(styrene-r-diene) (PS-co-PD) and hydrophylic poly(glycidol) (PG) blocks.

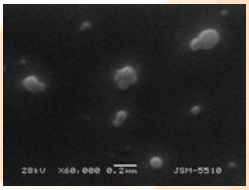
1. Synthesis

Anionic polymerization

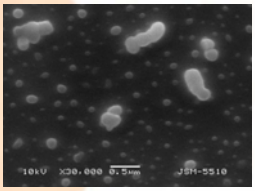


Copolymer composition	PS/PD ratio (mol %)	PEEGE block	Copolymers	
		M_n ^{1}H NMR (g/mol)	M_n SEC (g/mol)	M_w/M_n SEC
PS-co-PI-b-PEEGE	93/**7**	2700	15 300	1,25
PS-co-PI-b-PEEGE	93/**7**	3500	17 300	1,21
PS-co-PI-b-PEEGE	93/**7**	6900	20 000	1,20
PS-co-PI-b-PEEGE	86/**14**	550	20 100	1,20
PS-co-PB-b-PEEGE	85/**15**	1700	22 800	1,19
PS-co-PB-b-PEEGE	85/**15**	3700	25 600	1,22
PS-co-PB-b-PEEGE	85/**15**	7800	26 100	1,21
PS-co-PB-b-PEEGE	75/**25**	7600	26 900	1,24

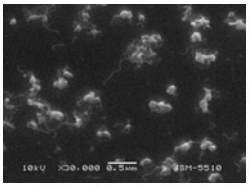
2. Micellization in different organic solvents. SEM analyses



PS-co-PB-b-PG 7,8K
THF

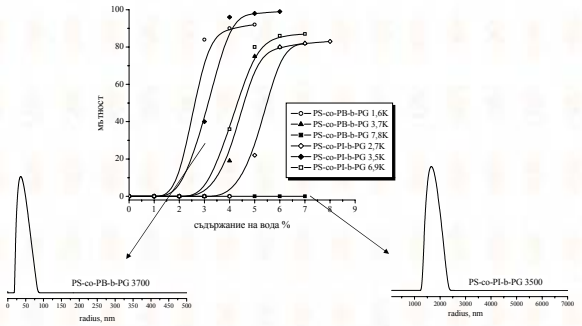


PS-co-PB-b-PG 7,8K
DO

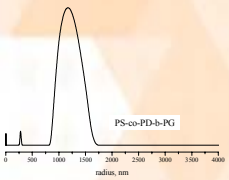


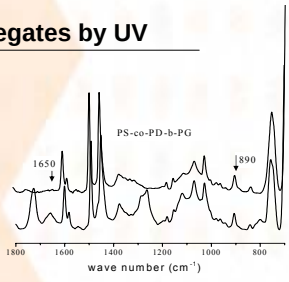
PS-co-PI-b-PG 6,9K
DMF

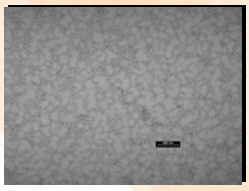
3. Turbidity measurements

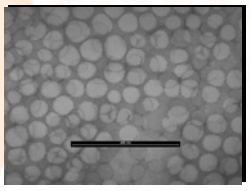


5. Stabilization of aggregates by UV

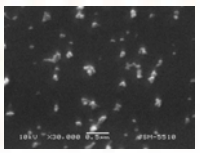




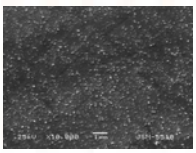




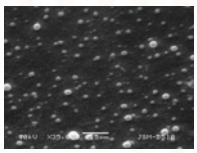
4. Role of water additive



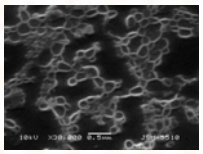
PS-co-PB-b-PG 8K
DMF



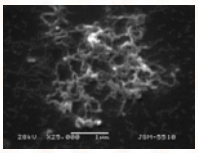
PS-co-PI-b-PG 7K
DMF



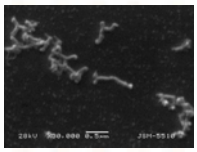
PS-co-PB-b-PG 4K
DMF



PS-co-PB-b-PG 8K
DMF/water



PS-co-PI-b-PG 7K
DMF/water



PS-co-PB-b-PG 4K
DMF/water

Conclusion

✓ A series of PS-co-PD-b-PG amphiphilic copolymers have been prepared.
✓ Investigations on the association and self-assembly of copolymers in dilute organic and in mixed organic/water solutions have been carried out. Amphiphilic block copolymers self-assemble into various shape and size of the micelles/aggregates depending on the hydrophobic/hydrophilic blocks ratio and on the solvents composition .
✓ Stabilized nano- and microsized morphologies have been obtained by UV-irradiation of copolymers solutions. The structures, visualized by SEM, are obtained as a result of cross-linking at the double bonds of isoprene (butadiene) fragments available in the copolymer chain as proved by NMR and FTIR spectral studies.

Funding

European Social Fund, Operational Program "Human resources development - BG051PO001/07/3.3-02 under project "Support for the development and realization of PhD-students, post-docs and young researchers in the field of polymer chemistry, physics and engineering".
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AMPHIPHILIC POLY(D- OR L-LACTIDE)-*b*-POLY-(*N*,*N*-DIMETHYLAMINO-2-ETHYL METHACRYLATE) BLOCK COPOLYMERS: CONTROLLED SYNTHESIS, CHARACTERIZATION AND STEREOCOMPLEX FORMATION

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[2]Laboratory of Polymeric and Composite Materials, University of Mons-Hainaut, Place du Parc 20, B-7000 Mons, Belgium

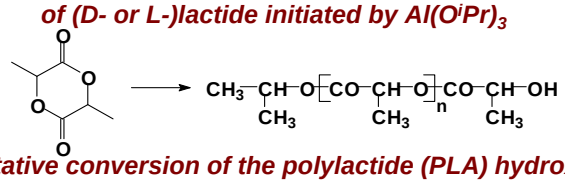
AIM To synthesize novel well-defined amphiphilic poly(D-lactide)-*b*-poly(*N*,*N*-dimethylamino-2-ethyl methacrylate (PDLA-*b*-PDMAEMA) and poly(L-lactide)-*b*-poly(*N*,*N*-dimethylamino-2-ethyl methacrylate) (PLLA-*b*-PDMAEMA) copolymers and to form a stereocomplex.

INTRODUCTION

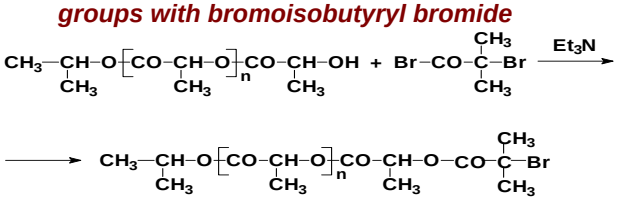
Poly(lactide)s (PLA) are biodegradable, biocompatible aliphatic polyesters, nontoxic to the human body, produced from annually renewable resources. Optically active PLLA and PDLA homopolyesters are able to form stereocomplex. Stereocomplexes are characterized by higher physical and chemical stabilities. The presence of an ionogenic block enables further modification of the polymer backbone to be performed. A very promising approach for imparting antibacterial, haemostatic and anticancer properties to the surface of PLA-based materials is its modification with PDMAEMA chains.

Synthesis strategy :

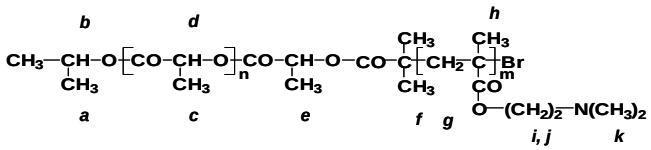
i) controlled ring-opening polymerization (ROP) of (D- or L-)lactide initiated by Al(O^{i}Pr)$_3$



ii) quantitative conversion of the polylactide (PLA) hydroxyl end-groups with bromoisobutyryl bromide



iii) atom transfer radical polymerization (ATRP) of DMAEMA



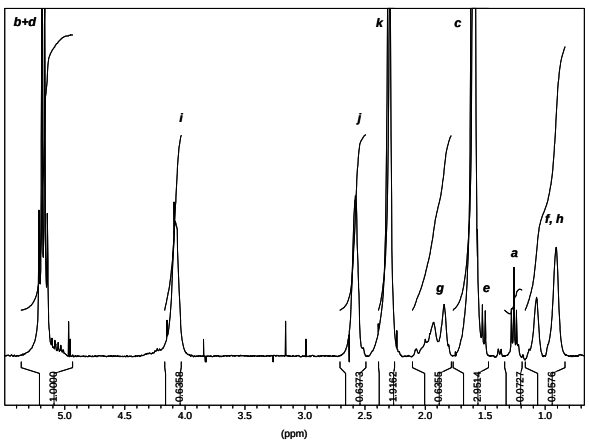
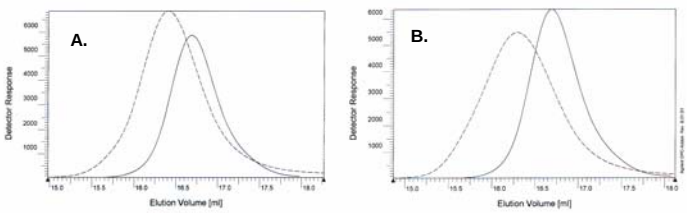


Table 1. Macromolecular characteristics of PLA-*b*-PDMAEMA

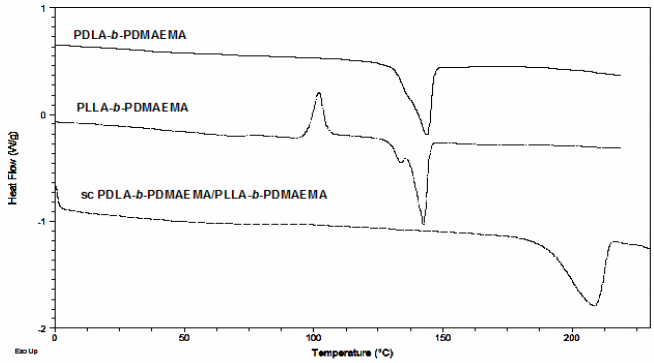
Copolymers	DP PDMAEMA block[a]	Conv. [%][b]	Yield [%][c]	*f* [d]	M_n^{exp}, g/mol		PI[e]
					PDMAEMA block[a]	PLA block[e]	
PDLA-*b*-PDMAEMA	32	0.80	80	0.70	5030	4180	1.39
PLLA-*b*-PDMAEMA	34	0.80	82	0.66	5340	4220	1.42

Size exclusion chromatography



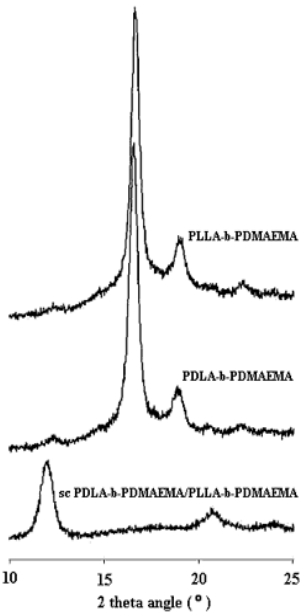
SEC of **A.** PDLA-*b*-PDMAEMA (dashed line) and PDLA-Br macroinitiator (solid line) and **B.** PLLA-*b*-PDMAEMA (dashed line) and PLLA-Br macroinitiator (solid line).

Thermal analyses



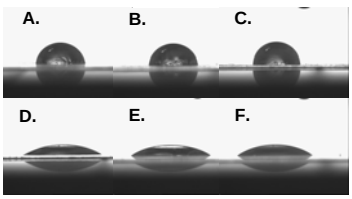
DSC curves of PDLA-*b*-PDMAEMA, PLLA-*b*-PDMAEMA and stereocomplexed "sc" PDLA-*b*-PDMAEMA/PLLA-*b*-PDMAEMA [PDLA-block/PLLA-block = 1/1 (mol/mol)] films cast from CH_2Cl_2. Heating rate -10 °C/min under N_2 flow. First heating run.

X-Ray Diffraction analyses



XRD traces of PLLA-*b*-PDMAEMA, PDLA-*b*-PDMAEMA and "sc" PDLA-*b*-PDMAEMA/PLLA-*b*-PDMAEMA films.

Water contact angle measurements



Recorded images of water deposited on the surface of films of: A. PDLA, B. PLLA, C. "sc" PDLA/PLLA, D. PDLA-b-PDMAEMA, E. PLLA-b-PDMAEMA, F. "sc" PDLA-b-PDMAEMA/PLLA-b-PDMAEMA.

CONCLUSION

Well-defined PDLA-*b*-PDMAEMA and PLLA-*b*-PDMAEMA diblock copolymers were successfully synthesized. The interest for these diblock copolymers relies upon the presence of a biodegradable and biocompatible polylactide block that is able to form strong stereocomplexes and a water soluble poly(aminomethacrylate) block known for its inherent biological activity. These novel materials that are potential candidates for biomedical applications such as wound healing and local cancer treatment.

ACKNOWLEDGEMENTS

The authors are much indebted to the bilateral cooperation between the Bulgarian Academy of Sciences and Commissariat General aux Relations Internationales (CGRI, Brussels). Financial support from the Bulgarian Fund Scientific Research (Grant DO 02-164/08) is acknowledged.

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Preparation and characterization of poly (lactic acid) nanocomposite foams by melt intercalation

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Introduction

Poly (lactic acid) (PLA) is biodegradable aliphatic polyester derived from renewable resources that has gained much interest in recent years. PLA could become a competitive alternative to traditional commodity plastics for everyday applications from an environmental standpoint. The development of commercial applications from PLA requires improvement of its mechanical properties, crystallization and processing behaviour. The mechanical properties and degradation rates of PLA depend on their morphology and crystallinity. One approach to improve the mechanical properties is to incorporate the silicate layers into the polymer and create a polymer-clay nanocomposite.
The aim of this work is thus to analyze the nanostructure and the structure /property relationships of nano-biocomposites elaborated by a melt intercalation method.

Materials and experimental procedure

Granulated PLA has been a commercial product of the Biomer (Krailling-Germany) with the tradename "Biomer 9000L". Cloisite 30B (product of Southern Clay Company), which is organically modified montmorillonite (MMT), were chosen as the clay for the nanocomposites. Cloisite 30B organoclay and PLA were dry under vacuum at 80°C for 12 h. Then 0, 1, 3, 5, 7 and 9% weight ratios of organoclay and PLA were dry mixed before melt blending. The melt-blending process was carried out in brabender mixer at 190°C and 50rpm for 20 min. The mixed nanocomposites were cooled at room temperatures.

Results and Discussion

Fig.1 shows the DSC resluts of PLA/MMT nanocomposites. Heat of cold crystallization ΔH_{cc} decreases with increasing MMT concentration due to reduced mobility of PLA chains and therewith connected retarded cold crystallization. Heat of melting ΔH_m reflecting total crystallinity of the sample shows maximum for PLA-5. The sum of these two values is proportional to the original crystallinity of as received samples. It shows a pronounced maximum for PLA/MMT 5 wt.%. Glass transition temperature T_g is slightly higher for neat PLA, which indicates that its chains are more closely packed in the glassy state; however, after crossing T_g, their mobility is higher (higher ΔH_{cc}). There is no trend in peak temperature of cold crystallization T_{cc}. The melting endotherm of neat PLA shows single maximum reflecting uniform distribution of thickness of crystal lamellae. Melting endotherms of the PLA/MMT samples show some secondary maxima or humps pointing to multimodal distribution of lamellae.

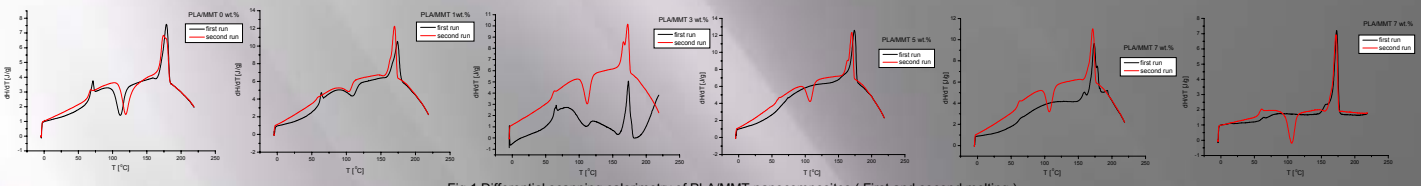

Fig.1 Differential scanning calorimetry of PLA/MMT nanocomposites (First and second melting)

Similarly to the first runs, the highest heat of cold crystallization ΔH_{cc} was found for neat PLA. However, unlike the first runs, intensive cold crystallization was also detected for all PLA-MMT samples. Heat of melting ΔH_m shows maximum for PLA/MMT 1 wt.%. If we assume that the samples after the first heating run are amorphous, the sum of the three values $\Delta H_{mc} + \Delta H_{cc} + \Delta H_m$ should be zero. This is, however, true for neat PLA only; all PLA/MMT samples show significant positive deviations. Possible explanation could be as follows: On melting during the first run, PLA chains are released from the organized composite structure and subsequently undergo melt and cold crystallization during cooling and reheating. However, some chains still remain partially trapped in the composite structure and crystallize much slower. A flat exotherm of this slow crystallization is probably imposed under major part of the cooling and reheating traces and is not detected by DSC. It is also possible that the two-minute keeping of the samples at 220°C after the first heating run is insufficient for complete removal of all crystallites which then finally melt on reheating in the second run. Most probable is combination of both these factors.
To glass transition temperatures in the second runs applies the same as to those in the first runs. Higher T_g of neat PLA also results in higher peak temperature of its cold crystallization T_{cc}. Melting endotherms of all samples in the second run show two peaks (or main peak and a hump) indicating bimodal distribution of lamellae. Both peaks of neat PLA are found at significantly higher temperatures, which suggests higher perfection of the crystallites.

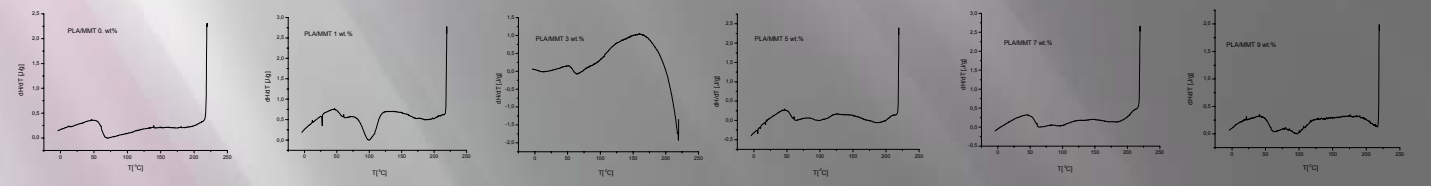

Fig.2 Differential scanning calorimetry of PLA/MMT nanocomposites (crystallization)

Fig.2 shows the DSC cooling results of PLA/MMT nanocomposites. Neat PLA shows no exotherm of melt crystallization unlike the PLA/MMT samples where a pronounced maximum was found for heat of melt crystallization ΔH_{mc} of PLA/MMT 1 wt.% – its concentration of MMT is probably optimal for nucleation of melt crystallization. Glass transition temperature T_g is slightly higher for neat PLA; its chains obviously pack more easily on cooling to reach the glassy state. No trend was found in peak temperature of melt crystallization T_{mc} of PLA/MMT samples. The obtained DSC data for all considered sample are summarized in Table 1 and Table 2.

Table 1

	1st run			Cool	2nd run		
Sample	ΔH_{mc}	ΔH_m	Δ	ΔH_{mc}	ΔH_{cc}	ΔH_m	Δ
PLA/MMT 0 wt.%	-25.3	35.0	9.7	0.0	-33.9	34.5	0.6
PLA/MMT 1 wt.%	-17.9	37.5	19.6	-14.3	-12.6	43.5	16.6
PLA/MMT 3 wt.%	-15.2	38.8	23.6	-1.7	-25.5	36.4	9.2
PLA/MMT 5 wt.%	0.0	49.5	49.5	-2.4	-22.5	39.3	14.4
PLA/MMT 7wt.%	0.0	42.1	42.1	-1.2	-23.1	36.4	12.1
PLA/MMT 9 wt.%	0.0	38.9	38.9	-3.4	-27.7	37.3	6.2

Table 2

	1st run						Cooling		2nd run			
	T_g	T_{cc}	T_m				T_g	T_{mc}	T_g	T_{cc}	T_m	
Sample			1	2	3	4					1	2
PLA/MMT 0 wt.%	65.9	111.4	-	-	178.7	-	61.5	-	64.4	119.4	175.5	178.0
PLA/MMT 1wt. %	60.4	109.7	166.0	174.0	-	-	54.3	100.1	56.3	103.9	163.0	169.7
PLA/MMT 3 wt.%	61.7	110.0	-	173.5	178.6	-	58.4	96.5	59.5	112.2	166.2	172.5
PLA/MMT 5 wt.%	63.8	-	157.0	174.0	-	-	55.7	100.3	56.5	107.6	163.5	170.1
PLA/MMT 7.wt%	62.2	-	158.4	173.6	178.0	193.7	57.3	97.5	59.6	107.0	165.0	171.6
PLA/MMT 9wt.%	61.6	-	157.0	173.0	-	-	53.8	97.4	57.3	106.0	163.5	171.8

Conclusions

The organophilic clay used in this study enhanced the crystallization rate and improved the perfection of the PLA crystals. An Interesting fact is unusual higher degree of crystallinity of these samples. Phenomenon can be attributed to montmorillonite (MMT) particles. It is well known that the MMT particles can change the rate of primary nucleations. The Surfaces of MMT layers serve as primary nucleations centers leading to an enhanced total crystallinity of the polymer. Heat of cold crystallization ΔH_{cc} decreases with increasing MMT concentration due to reduced mobility of PLA chains and therewith connected retarded cold crystallization.

Acknowledgment

Ph. Ublekov thanks the European Social Fund, the Structural Funds - Operational Programme "Human Resources" for financial support in the frame of the Project "Support for the development and realization of PhD-students, post-docs and young researchers in the field of polymer chemistry, physics and engineering", Grant № BG051PO001/07/3.3-02/51 51.

Copolymerization of benzil with styrene

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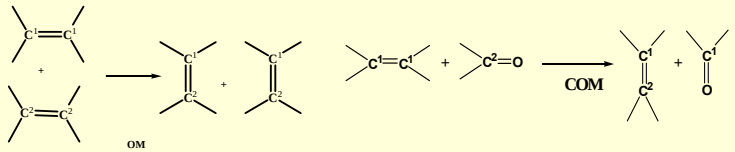
INTRUDUCTION

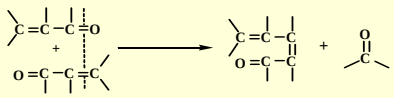
A new carbon-carbon double bond formation reaction, namely the carbonyl-olefin metathesis (COM), was discovered at the Institute of Polymers, BAS[1/]. There is a formal similarity between the general schemes of this reaction and the olefin metathesis (OM): one carbon atom in the scheme of OM is replaced with an oxygen atom (Sch. 1)



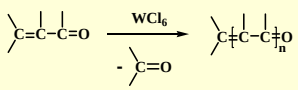
Scheme 1

The new reaction is performed successfully only when the two functional groups belong to one molecule and are conjugated. The molecules of the substituted propenones (chalcones) are up to this requirement.

In this case the COM is a propagation step of a polycondensation reaction (Sch.2). The result of this polycondensation process is a substituted polyacetylene (Sch.3).

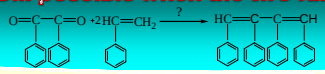


Scheme 2



Scheme 3

General Question: Is COM possible when the two functional groups are not in the same molecule?



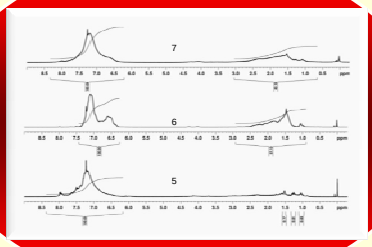
EXPERIMENTAL RESULTS

➢ *Experimental conditions: t =90C, τ=3h, monomer- Benzil, comonomer – Styrene, catalyst - WCl_6,solvent- Chlorbenzene*

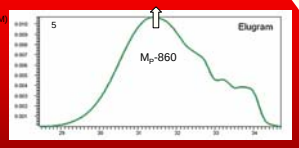
	Monomer: Comonomer: Catalyst (Molar radio)	Method of adding	Yield insoluble part in EtOH (g)
1	0:2:1	Styrene is added drop wise after the solution became red	-
2	0:2:0	Styrene is added drop wise after the solution become red	-
3	0:2:0,1	Styrene is added drop wise after the solution become red	0.086
4	1:0:1	Styrene is added drop wise after the solution became red	traces
5	1:2:1	Styrene is added drop wise after the solution became red	0.200
6	1:2:0,1	Styrene is added drop wise after the solution became red	0.265
7	1:2:1	The reactants are mixure all at once	0.180

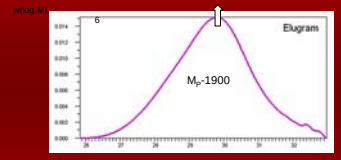
Analyses of insoluble products obtained via copolymerization of benzil with styrene

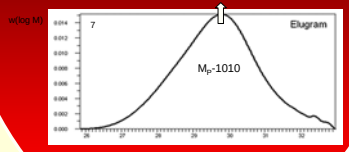
[1] NMR spectra



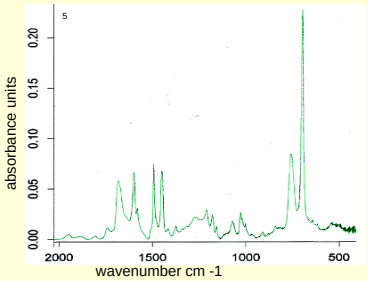
GPC products are oligomers

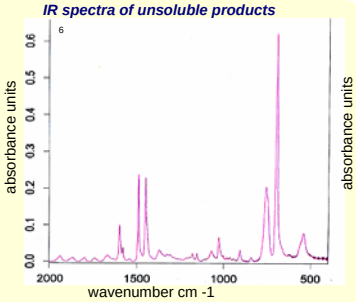


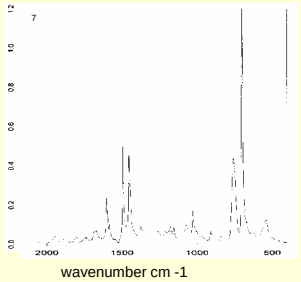




IR spectra of unsoluble products



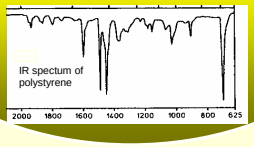




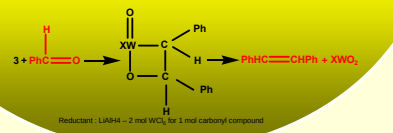
WHAT DOES THE LITERATURE SAY?

SIMULTANIOUS COORDINATION AND CATIONIC POLYMERIZATION IN WCL_6 CATALYZED COPOLYMERIZATION OF PHENYL ACETYLENE STYRENE **(T Masuda and T. Hugashimira , Macromolecules, 12,9-12(1979).**

WCl_6 as effective catalyst for polymerization of phenylacetilene proceed s by coordination (metathesis) mechanism. On the other hand WCl_6 has been know as a Lewis acid. For example, it can catalyze the cationic polymerization of styrene. Coordination and cationic polymerization proceed simulations in WCl_6- catalyzed co-polymerization of phenylacetylene with styrene and that formed polymerization gives poly(phenylacetylene) and the letter a copolymer of styrene with phenylacetylene



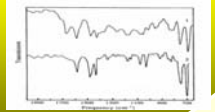
REDUCTIVE COUPLING OF CARBONYL COMPOUNDS TO OLRFINS BY TUNGSTEN HEXACHLORIDE - LITIUM ALUMINUMHYDRIDE AND SOME TUNGSTEN AND MOLYBDENUM CARBONYLS. **(Y.Fujivara, 8R.Ishikawa, F. Akijama, and S. Reranishi, J. Org. Chemistry, 43, 2477-2480 (1978)).**



POLYMER FORMATION VIA REDUCTIVE COUPLING OF A DIKETONE BY METATHESIS CATALYTIC SYSTEMS **(C. Jossifov,Eur. Polymer. J. 43, 883-885 (1998)**

We have succeeded unprecedentedly to carry out reductive coupling polymerization of the conjugated dicarbonyl compound benzyl ender the influence of the Friedel-Crafts matathesis catalytic system WCl6 + AlCl3. In this case the quantity of the transition metal compound is less than the quantity of the Ti reagent used forMcMury reaction. The very new moment here is the absence of reducing agent.

IR-spectra of polydiphenylacetylene with carbonyl end groups, polyphenylacetylene with olefin end groups



CONCLUSION: Instead of COM WCL_6 promotes other reactions (homo- and co-polymerization of styrene and benzil)

This research work was supported by Bulgarian Ministry of Education and Science, Structural Funds and Educational Programs Directorate, Project "Support for the development and realization of PhD-students, post-docs and young researchers in the field of polymer chemistry, physics and engineering", **Grant № BG051PO001/07/3.3-02/51 51.**

Термична стабилност на нанокомпозити на базата на фунционализирани полиетилени

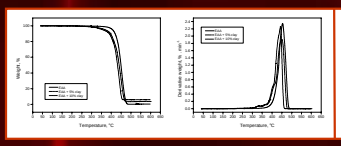
Яна Георгиева Пенева-Стоянова

Институт по полимери – БАН
Лаборатория "Структура и свойства на полимерите"

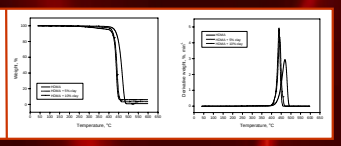
Нанокомпозитите са получени при смесване в стопилка на един от следните полимери с клей - органично модифициран монтморилонит - Клоизит 15А
Полимери:
Съполимери на етилен с акрилова киселина
Съполимер етилен-глицидилметакрилат
Полиетилен висока плътност присаден с малеинов анхидрид

ВПМА се използва като съвместител за получаване на нанокомпозити на базата на полиетилен висока плътност.

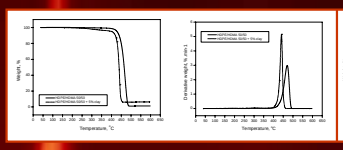
ТГ, ДТГ в инертна атмосфера



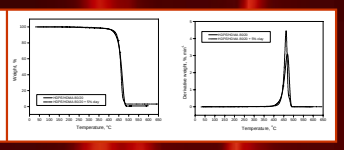
ЕАК



ВПМА

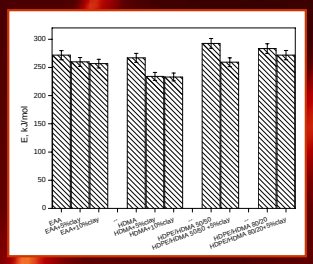


ВП/ВПМА 50/50



ВП/ВПМА 80/20

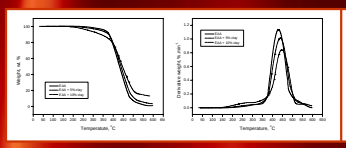
От кривите са определени следните кинетични параметри:
T_{10}, T_{50}, $T_{макс}$, степен на превръщане при 450°C, К /%/мин/, Е /kJ/mol/
Метод на инфлексната точка:
$E = nRT_m^2 (d\alpha/dT)_m (1 - \alpha_m)^{-1}$,
където m е индекс характеризиращ температурата, при която съществува максимум $d\alpha/dT$, т.е. $d^2\alpha/dT^2 = 0$
n е определен според уравнението на Дойл: $n^{1/1-n} = (1 - \alpha_m)$



Анализът на кинетичните параметри на неизотермична деструкция на пробите в азотна атмосфера потвърди, че ненапълнените проби са термично по-стабилни от напълнените.

Намаляването на термичната стабилност е по-силно изразено при пробите с по-голяма степен на разслояване на ламелния силикат – на базата на ВПМА.

ТГ, ДТГ във въздушна атмосфера



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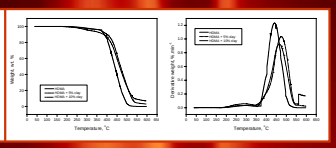
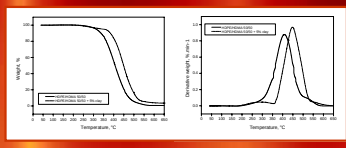
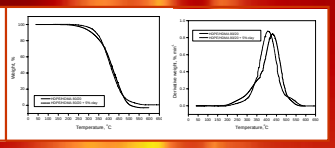


ВПМА



ВП/ВПМА 50/50



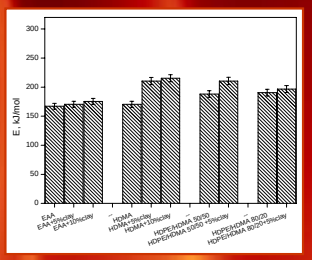
ВП/ВПМА 80/20

От кривите са определени същите параметри.

Термичната стабилност във въздушна среда на нанокомпозитите е по-голяма от тази на чистите полимери.

Този резултат е интерпретиран чрез бариерния ефект на силикатния остатък за проникването на кислород в материала.

Повишаването на термичната стабилност е по-чувствително за нанокомпозитите с разслоена структура (ВПМА), тъй като разслоените силикатни слоеве осигуряват по-добър бариерен ефект.



Термичната стабилност на нанокомпозитите във въздушна атмосфера силно се подобрява.
Този ефект е по-силно изразен при нанокомпозитите с разслоена структура ,
отколкото при тези с включена структура.

Благодарности на:

Договор № BG051PO001/07/3.3-02/51
" Подкрепа за развитие и реализация на докторанти, пост-докторанти и млади учени в областта на полимерната химия, физика и инженерство"

Bendamustine - Polyphosphoesters Delivery Systems

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Summary: Novel water soluble polymer complexes of bendamustine hydrochloride, a bifunctional alkylating agent with antimetabolic and cytotoxic activity, was developed using a biodegradable polymer carriers – poly(oxyethylene H- phosphonate) **(1)**, poly(methyloxyethylene phosphate) **(2)** and poly(hydroxyoxyethylene phosphate) **(3)**. The structure of the complexes formed is elucidated by ^{1}H, ^{13}C, ^{31}P NMR and FT-IR spectroscopy. Bendamustine hydrochloride was immobilized onto polyphosphoesters via covalent, ionic and hydrogen boning. ***The chemical stability*** of bendamustine hydrochloride in the novel complexes was studied by HPLC analysis. The results from the HPLC indicate that in neutral (pH 7) media bendamustine hydrochloride in the polymer complexes is more stable than the pure substance. ***In vitro tests*** on KE-37 human leukemic cells displayed a significant increase (particularly in the low concentration range) of the antineoplastic effect of bendamustine after immobilization, a promising feature that may promote application impact.

AIM: To prepare efficacious water-soluble polymer complexes of bendamustine through immobilization of the drug onto polyphosphoesters used as polymer carriers

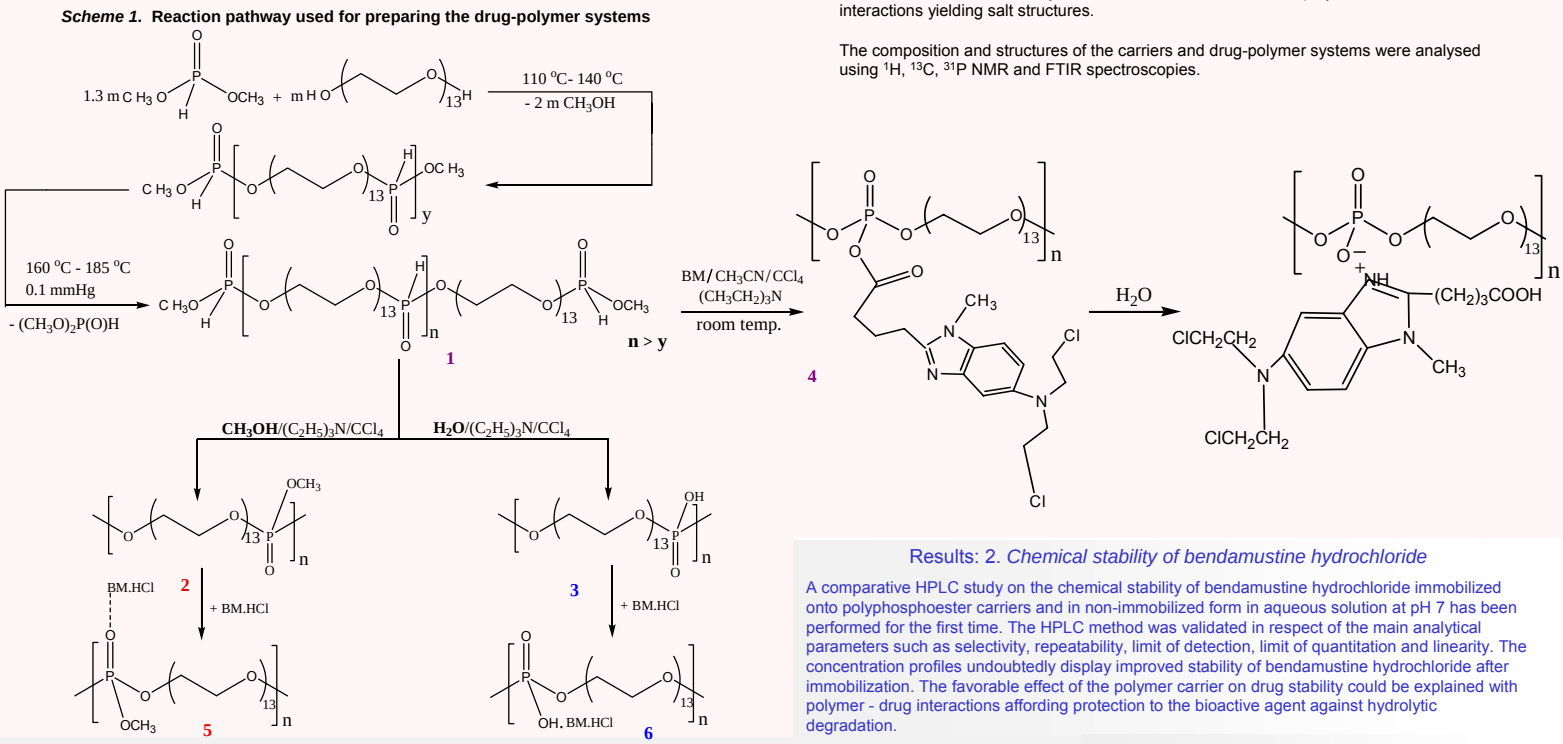
Introduction: Many investigations in cross- and inter- discipline areas have been focused to create therapeutic strategies and concepts for current life - threatening diseases. Polymer chemists have been actively involved in designing polymer materials to overcome some major problems in cancer therapy, such as: the toxic side effects of the drugs upon the normal cells, the duration of drug action, the resistance to the medication, protection of the patient's immune system, etc.

Polymers with repeating phosphoester bonds in the backbone are structurally versatile, and biodegradable through hydrolysis and possibly enzymatic digestion at the phosphoester linkages under physiological conditions. These biodegradable polymers are appealing for biological and pharmaceutical applications because of their potential biocompatibility and similarity to bio-macromolecules such as nucleic acids. The poly(oxyethylene phosphonate)s and poly(oxyethylene phosphate)s are members of the polyphosphoester family. They are especially attractive materials due to the relative easiness of their preparation from commercially available building blocks (PEGs), the variety of molecular weights and number of reactive centers attainable, and the relatively narrow molecular weight distributions of the polymers formed [1, 2].

Results: 1. Bendamustine-polyphosphoester delivery systems

Synthesis of the polymer carriers *(Scheme 1):*
Polymer 1 – the precursor poly(oxyethylene H-phosphonate) was obtained via polytransesterification of dimethyl H-phosphonate with PEG 600.The number average molecular weight of POEPh of 7200 g/mol was calculated using ^{1}H and ^{31}P NMR data.
Polymer 2 - poly(methyloxyethylene phosphate) was obtained from Polymer 1 and methanol via the Atherton-Todd reaction
Polymer 3 - poly(hydroxyoxyethylene phosphate) was obtained from Polymer 1 and water via the Atherton-Todd reaction

Scheme 1. **Reaction pathway used for preparing the drug-polymer systems**



***Immobilization of bendamustine hydrochloride onto polyphosphoesters (Scheme 1)*:**
Product 4 - Bendamustine hydrochloride was immobilized onto polymer **1** using Atherton - Todd reaction conditions (Scheme 1). IR, ^{1}H, ^{13}C, ^{31}P NMR spectroscopic data confirmed the structure of the reaction product **4**. Bendamustine was attached to the polyphosphoester via covalent bond**.**
Product 5 - Bendamustine hydrochloride was immobilized onto polymer **2** via hydrogen bonding between the strongly polar phosphoryl (P=O) groups in the carrier phosphoester segments and drug carboxylic groups.
Product 6 - Bendamustine hydrochloride was immobilized onto polymer **3** via electrostatic interactions yielding salt structures.

The composition and structures of the carriers and drug-polymer systems were analysed using ^{1}H, ^{13}C, ^{31}P NMR and FTIR spectroscopies.

Results: 2. *Chemical stability of bendamustine hydrochloride*

A comparative HPLC study on the chemical stability of bendamustine hydrochloride immobilized onto polyphosphoester carriers and in non-immobilized form in aqueous solution at pH 7 has been performed for the first time. The HPLC method was validated in respect of the main analytical parameters such as selectivity, repeatability, limit of detection, limit of quantitation and linearity. The concentration profiles undoubtedly display improved stability of bendamustine hydrochloride after immobilization. The favorable effect of the polymer carrier on drug stability could be explained with polymer - drug interactions affording protection to the bioactive agent against hydrolytic degradation.

Results: 3. Cytotoxic efficacy of the bendamustine-polyphosphoester systems

Bendamustine hydrochloride alone exerted concentration dependent cytotoxic efficacy against KE-37 leukemia cells (Fig. 2) with an IC_{50} value between 50 and 100 μM after 72 h of incubation. Immobilization of bendamustine onto polyphosphoesters induced cytotoxic effect, which was greater in the all of three studied polymer-drug complexes than that of bendamustine itself. Moreover, the bounded drug exerted enhanced cytotoxic effect in the lower concentration range – about 2 fold increase at equivalent concentration of 25÷50 μM. A parallel MTT assay on the same cells was performed with the polymer carriers. They caused a slight cytotoxic effect and did not display any significant decrease in cell viability even at high concentrations.

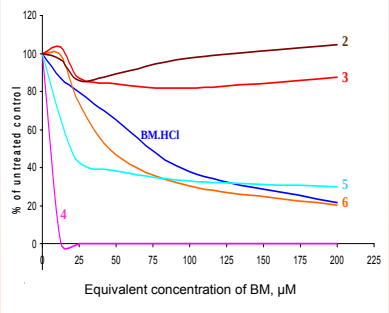


Figure 2. Concentration dependence of the cytotoxic effect of: - polymer 2; - polymer 3; - product 4; - product 5; - product 6; - bendamustine hydrochloride on KE-37 leukemia cells (MTT-dye reduction assay).

In conclusion: Data about the antineoplastic effect *in vitro* indicate a pronounced increase of bendamustine activity after immobilization. The augmented efficacy of the polymer conjugates could be made clear by better membrane transfer or polymer mediated endocytosis**.**The concentration profiles undoubtedly display higher stability of bendamustine hydrochloride after immobilization compared to the non-immobilized drug. The obtained experimental data and their analysis could contribute in the future investigation on the mechanism of bendamustine action and could have a practical impact in terms of a manageable hydrolytic profile of the drug.

Acknowledgment: **The authors would like to gratefully thank to the Structural Funds and Educational Programs Directorate, Grant "BG051PO001/07/3.3-02/51" for the financial support. Bulgaria, Sofia, 2009**

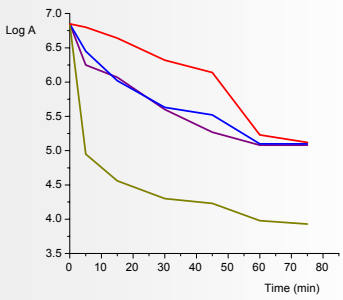


Figure 1. Stability data of **bendamustine hydrochloride; product - 4; product 5; product 6** at pH 7.

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[1] Troev K., Chemistry and Application of H-phosphonates, Elsevier, Amsterdam, **2006.**
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[3] Konstantinov S.M., Kostovski A., Topashka-Ancheva M., Genova M., Berger M.R., Cytotoxic efficacy of bendamustine in human leukemia and breast cancer cell lines. *J Cancer Res Clin Oncol.* **2002**, 128(5), 271-278.

New functional polyphosphoesters

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Introduction: Synthesis of functional and reactive polymers is one of the intensive research areas of polymer science [1]. Polymers with highly reactive groups are attractive materials for bio-medical applications due to possibility polymer conjugates of bioactive molecules, drugs and biopharmaceuticals to be obtained under mild reaction conditions [2]. Polymers with phosphoester (P–O–C) repeating linkages in the backbone are particularly interesting in drug delivery research because of their biocompatibility and structural similarity to natural biomacromolecules like nucleic acids [3]. The biodegradability of these polyphosphoesters is induced by hydrolysis or enzymatic scission of the ester bonds leading to harmless low molecular weight products. Poly(alkylene H-phosphonate)s are polymers with defined structure [4]. Macromolecules are built up of alkylene blocks linked by phosphoester groups and strictly alternating reactive sites that can be used to attach desired compounds. Increasing attention has been paid to polymers bearing five-membered cyclic carbonate functionalities in the side chain [5]. The 1,3-dioxolan- 2-one ring displays high chemo-selective reactivity towards aliphatic amines and can be applied for immobilization of drugs, enzymes, cells onto polymers bearing 1,3-dioxolan-2-one moieties

***To this end*:** **1)** the precursor poly(oxyethylene H-phosphonate) was modified via addition of the polymer P–H groups to the vinyl group of the cyclic carbonate derivative or applying the Atherton - Todd reaction yielding methyl phosphate moieties (P–OCH_3).

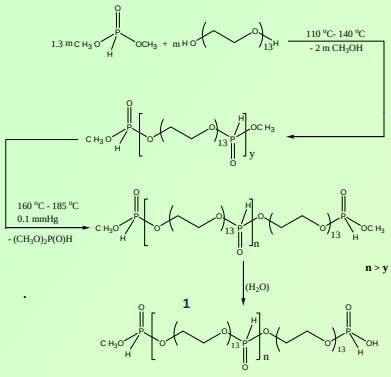
2) the aminolysis of the 1,3-dioxolan-2-one rings afforded a polyphosphoester bearing hydroxyurethane fragments in the side chains. Different compounds such as peroxides, KF and CdI_2 were studied as a promoters of the addition reaction of P–H groups to the vinyl group of 4-ethenyl-1,3-dioxolan-2-one. The reaction proceeded with satisfactory yield in the presence of tert-butyl peroxybenzoate

Aim: synthesis and structure elucidation of novel multifunctional polyphosphoesters bearing P–H or P–OCH_3 groups in the main chain and 1,3-dioxolan-2-one rings or hydroxyurethane fragments attached to the polymer backbone through a P–C bond.

Results and discussion

1) Synthesis and characterization of poly(oxyethylene H-phosphonate), 1

Poly(oxyethylene H-phosphonate) **1** was synthesized via polytransesterification reaction of dimethyl H-phosphonate with poly(ethylene glycol) with number average molecular weight 600 g/mol (PEG 600). The analyses of ^1H, ^{13}C and ^{31}P NMR spectra of polymer **1** confirm the structure suggested in the ***Scheme 1***. **The number average molecular weight (Mn) of the polymer product 1** of Mn = 13 500 g/mol was obtained on the basis of the ^1H and ^{31}P NMR spectral data. GPC measurements confirmed independently the polymer character of **1** displaying good correlation with the NMR data.



Scheme 1. Reaction pathway used for preparing the poly(oxyethylene H-phosphonate)

In the second run (Experiment 2) the addition reaction was carried out in a closed glass reactor and a solvent with higher boiling point was used, i.e. p-xylene. The monomer - initiator solution was added in three portions at intervals of 1 h. Prior the addition of the following portion of the monomer - initiator solution a sample of the reaction mixture was withdrawn for GPC -analysis. The chromatograms of the starting polymer and those of the products at different stages of the reaction are given in Fig. 3

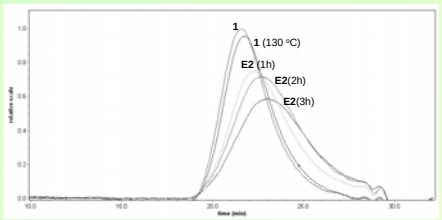


Fig. 3. GPC traces of: **1** – starting poly(oxyethylene H-phosphonate); **1**(130 °C) – poly(oxyethylene H-phosphonate) after melting at 130 °C,
and of the reaction mixture of 4-ethenyl-1,3-dioxolan-2-one and 1 under the conditions of Experiment 2 :
E2(1 h) – after 1 h reaction time
E2(2h) – after 2 h reaction time
E2(3h) – after 3 h reaction time

Two separate runs of the addition reaction were performed !!!

In the first one (Experiment 1) - the monomer and the initiator were dissolved in toluene and added drop-wise for a period of 4 h. The reaction system was under slow flow of inert gas. The reaction was carried out at 130 °C for a total reaction time of 5 h. The isolated product was analyzed by NMR spectroscopy to determine the conversion of the H-phosphonate groups in polymer 1 into phosphonate ones bearing ethylene-1,3-dioxolan-2-one moieties. In the ^1H NMR spectrum *(Fig. 1)* of the main product obtained under the reaction conditions of Experiment 1 new signals appeared in the region 1.40–2.03 ppm, which can be attributed to the hydrogen atoms in the PCH_2CH_2 segment formed by the addition of the P–H groups in the polymer to the vinyl groups in the cyclic carbonate derivative molecules. Moreover, the signals for the hydrogens from the CH_2=CH– group of 4-ethenyl-1,3-dioxolan-2-one in the region 5.4–5.9 ppm disappeared. The rest of the signals corresponding to protons in the backbone or in the carbonate cycles in the side chains of the modified polymer are also present in the spectrum.

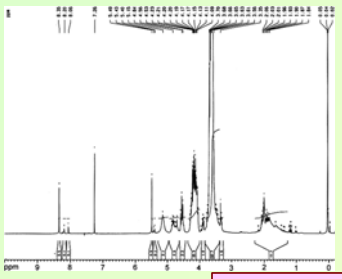
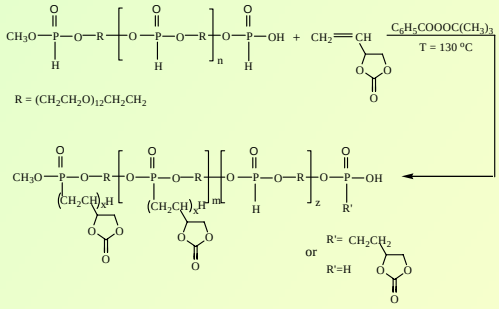


Fig. 1 ^1H NMR spectrum of polymer 2 (Experiment 1)

2) Synthesis of polyphosphoester bearing fivemembered cyclic carbonate and P– H groups, 2

The homolytic addition of the P–H groups of **polymer 1** to the double C=C bond of 4-ethenyl-1,3-dioxolan- 2-one was carried out under the following experimental conditions:
(i) equimolar ratio of the H-phosphonate groups in the polymer to the vinyl carbonate
(ii) tert-butyl peroxybenzoate as initiartor
(iii) a reaction temperature 130 °C

Scheme 2. Reaction pathway used for preparing the polyphosphoester bearing fivemembered cyclic carbonate and P–H groups - polymer 2



Direct evidence for the formation of the new P – C bond in the P–CH_2CH_2 fragment were the two doublets that appear in the $^{13}C\{H\}$ NMR spectrum of 2 *(Fig. 2)* at 20.65 ppm with coupling constant $^1J_{(P,C)}$ = 144.30 Hz assigned to P–CH_2 and at 27.11 ppm with $^2J_{(P,C)}$ = 4.9 Hz attributed to the other carbon atom in the P – CH_2CH_2 group. The signals at 72.39 ppm, 71.04 ppm and 154.60 ppm correspond to the carbon atoms in the 1,3-dioxolan-2-one ring *(Fig. 2)*

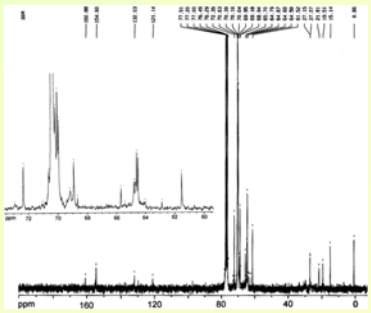


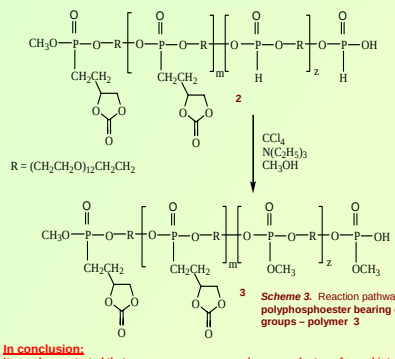
Fig. 2. $^{13}C\{H\}$ NMR spectrum of polymer 2

The mole fraction of the end monoester – P(H)OH groups increased in comparison with the starting polymer 1 implying chain breakdown. A value of Mn = 3 000 g/mol was calculated on the basis of the spectral data. GPC analysis of the product also evidenced decrease of the molecular weight Mn = 2 000 g/mol and increase of the polydispersity Mw/Mn = 3.33.

The change in the reaction conditions favored the isolation of higher molecular weight polymer – Mn = 8 400 g/mol and Mw/Mn = 1.62, in comparison with the product obtained under the conditions of **Experiment 1.** This result was also evidenced by the spectroscopic data. In the ^{31}P NMR spectrum of the product just a slight increase in the content of chain end groups was observed. A value of Mn = 7800 g/mol was calculated.

The experimental efforts were extended and the addition reaction was carried out in the presence of other catalysts i.e. $NaOCH_3$, CdI_2 and KF that could promote different reaction mechanism rather than free radical process. Unfortunately, none of the catalysts studied promoted the formation of the desired product. Insufficient yield was also obtained when benzoyl peroxide was used as initiator in the attempt to decrease the reaction temperature

3) Synthesis of a polyphosphoester bearing cyclic carbonate and methoxy groups – polymer 3 via transformation of P– H groups in polymer 2 into P–OCH_3 using Atherton – Todd reaction



Scheme 3. Reaction pathway used for preparing **polyphosphoester bearing cyclic carbonate and methoxy groups – polymer 3**

The P–H groups in the polymer 2 can be feasibly converted into P–OCH_3 groups at room temperature applying the Atherton–Todd reaction. At the first stage P–H groups of 2 were converted into P–Cl which at the second stage reacted with methanol to yield polymer 3. **The newly synthesized polyphosphoester 3 possesses two reactive functional groups – the carbonate cycle and the methoxy group. The carbon atom in the latter is an electrophilic centre able to participate in alkylation of amines and in a dealkylation reaction, i.e. reaction with metal salts or hydrogen chlorides. Both reactions can be used to convert the polymer into a polyanion or to attach bioactive substances via ionic bond. The carbonate cycle can react with amines imparting new functioanality.**

The interaction of the polyphosphoester 2 with phenylethylamine at room temperature proceeded through aminolysis of the cyclic carbonate residues and afforded a polyphosphoester 4, bearing hydroxyurethane and P–H groups ***(Scheme 4).*** In the IR spectrum of polymer 4 (Fig. 4) the absorption band at 1798 cm^{-1} for the C=O group of the cyclocarbonate disappeared and the new absorption band at 1712 cm^{-1} can be assigned to the C=O group of the urethane group. The absorption band at 3347 cm^{-1} can be assigned to the OH groups in the hydroxyurethane fragments that were formed in the result of the interaction of 1,3-dioxolan-2-one rings in polyphosphoester 2 with 2-phenyletylamine.The OH and P–H groups of polymer 4 are reactive groups and determine possibilities of 4 to react with isocyanates, esters, anhydrides, aldehydes, ketones and Schiff bases.

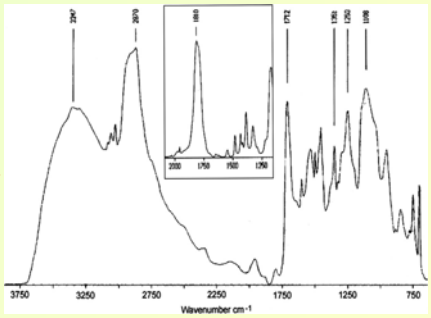
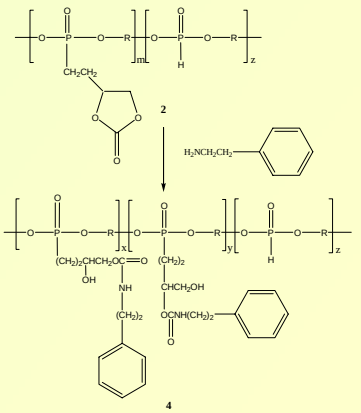


Fig. 4. IR spectrum of 4. The IR spectrum of 4-ethenyl-1,3-dioxolan-2-one in the region 2000–1200 cm^{-1} is presented

4) Synthesis of polyphosphoester bearing hydroxyurethane and P–H groups, polymer 4



Scheme 4. Aminolysis of the cyclic carbonate residues at polymer 2

In conclusion:
It was demonstrated that a common precursor polymer can be transformed into three different polyphosphoesters through feasible modification reactions. Preserving the main structure and composition of the backbone, new functional groups were incorporated into the macromolecules. These polymers possess common characteristics such as biodegradability and versatile reactivity that enables attachment of bioactive compounds via different immobilization patterns. In addition to the common features the modification imparts new properties to each of the products: (i) selective reactivity toward amines (ii) improved biocompatibility, (iii) control of hydrophilic-hydrophobic balance (iv) possibility to transform the obtained polyphosphesters into polycations or polyanions. The combination of valuable properties listed above renders these new polyphosphoesters as candidates for drug delivery applications.

References:
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[2] K. Troev, I. Tsatcheva, N. Koseva, R. Georgieva, I. Gitsov, *J. Polym. Sci.: Part A: Polym Chem.*, **2007**, 45, 1349
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Effects of amphiphilic diblock copolymers on the biopharmaceutical properties and pharmacokinetic behavior of DPPC liposomes

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INTRODUCTION

Liposomes are spherical, self-closed structures, composed of a lipid bilayer, which enclose a part of the surrounding water phase into their interior. Owing to their amphiphilic character, with hydrophobic bilayer and hydrophilic inner core, the liposomes have been considered to be well fitted to encapsulate and deliver a wide variety of therapeutic and diagnostic agents. The development of sterically-stabilized liposomes which are characterized by prolonged circulation time and bypassing the RES sequestration has increased considerably the popularity of liposomes as drug carriers. The steric stabilization is achieved by incorporation of polymer-derivatized phospholipids into the lipid bilayer, whereby PEG is the most extensively used polymer. A critical parameter for the steric stabilization is the maximum amount of PEG-lipids that can be incorporated into the phospholipid bilayer without the latter being damaged.

In the present contribution we use a new selection of copolymers to study their ability to sterically stabilize dipalmitoylphosphatidylcholine (DPPC): Cholesterol (Chol) liposomes as well as the performance of the latter as anticancer drug carriers. The copolymers are based on PEG and comprise different numbers, from 1 to 4, of lipid-mimetic anchors, which are schematically presented in Figure 1, and different PEG chain lengths, from 52 to 115 ethylene oxide (EO) units (Table 1).

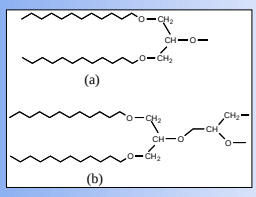


Fig. 1. Chemical structures of the lipid-mimetic anchors: 1,3-didodecyloxy-propane-2-ol (DDP), (a); 1,3-didodecyloxy-2-glycidyl-glycerol (DDGG) (b).

Table 1. Composition and nominal molecular weights of the polymer species.

Copolymer composition	Nominal molecular weight
$DDP(EO)_{52}$	2715
$DDP(EO)_{92}$	4475
$(DDGG)_2(EO)_{115}$	6028
$(DDGG)_4(EO)_{114}$	6952

EXPERIMENTAL METHODS

The phospholipids utilized in this study were purchased from Sigma Co. The copolymers were prepared according to procedures described in detail elsewhere (Rangelov St., et al, *Macromolecules,35,4770-4778*). Liposomes were prepared by hydration of a dry film cast from chloroform of DPPC, cholesterol and a copolymer in a chosen ratio. The resulting dispersions were subjected to eight freeze-thaw cycles and extruded 30 times through polycarbonate filters of pore size 100 nm. The final concentration was adjusted to 1.0 mM. Particle size and particles size distribution were determined on the DLS setup consisting of a 488 nm Ar ion laser and the detector optics with an ITT FW 130 photomultiplier and ALV-PM-AD amplifier-discriminator connected to an ALV-5000 autocorrelator built into a computer. Measurements were made at an angle of 90° and temperature 37°C. Cryo-TEM observations were conducted on a Zeiss EM 902 A instrument operating at 80 kV. The pharmacokinetics of the selected liposomal formulations was evaluated after i.v. injection of vesicles in Wister rats. Selected liposomal formulation were loaded with mitoxantrone hydrochoride and the loading efficiency as a function of copolymer composition and content was investigated. The cytotoxic activity of liposomal vs. free mitoxantrone was tested in a panel of human tumor cell lines using the MTT-dye reduction assay.

RESULTS AND DISCUSSION

- The utilized method of liposomal preparation is known to yield unilamellar liposomes with mean diameter of about 150 nm.
- Within the copolymer to DPPC ratios studied, the size distributions were monomodal for all tested formulations (fig.2).
- The size of the liposomes stabilized by copolymers containing one lipid-mimetic anchor per chain is found to decrease upon increasing the content of the copolymer intercalated in the liposome membrane, whereas that of liposomes stabilized by copolymers bearing more than one lipid-mimetic anchors is less affected (fig. 3a and 3b).
- The structural investigations carried out by cryo-TEM reveal formation of well-separated, intact, and predominantly spherical liposomes at lower copolymer contents up to 7.5 mol %. At a certain content, which is dependent on the copolymer composition, formation of openings in the bilayer membranes and discs is observed. A fraction of non-spherical, "flat" liposomes is formed upon the incorporation of copolymers containing short blocks of lipid-mimetic anchors at contents 7.5 mol % and above (fig.4), and by considering a large number of images their dimensions were estimated to ca. high 60nm ± 11nm, length 175nm ± 19nm and width 163nm ± 24nm.
- The pharmacokinetic study of DPPC liposomes plain or sterically stabilized with 5 mol % of conventional PEG-lipid DSPE-PEG2000 or $(DDGG)_4(EO)_{114}$ shows that vesicles stabilized with copolymer bearing four lipid mimetic units are characterized with better pharmacokinetic parameters (tabl. 2 and tabl. 3) and longer circulation life time (fig.5) as compared with plain liposomes and liposomes stabilized with conventional PEG-lipid.

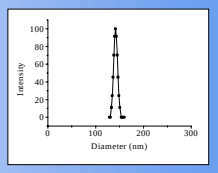
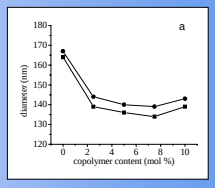


Fig. 2 Size distributions of DSPC:Chol liposomes containing 5 mol % $DDP(EO)_{92}$



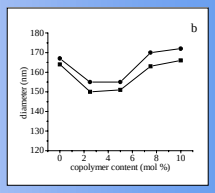


Fig. 3 Variations of the hydrodynamic diameters at an angle of 90° of series of DSPC:Chol lipsomes stabilized by (a) $DDP(EO)_{92}$, (b)$(DDGG)_4(EO)_{114}$ as a function of copolymer content at 25°C (squers) and 37°C (circles)

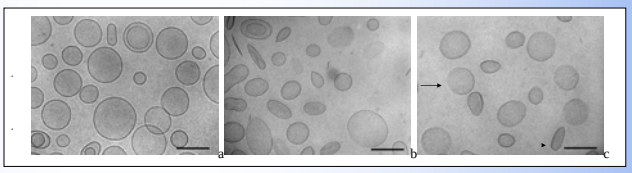


Fig. 4 Cryo-TEM images of samples based on DPPC:Chol at molar ratio 2:1 stabilized by $(DDGG)_4(EO)_{115}$ and $(DDGG)_4(EO)_{114}$: a) 2.5 mol % $(DDGG)_4(EO)_{114}$; b) 7.5 mol % $(DDGG)_2(EO)_{115}$ and c) 7.5 mol % $(DDGG)_4(EO)_{114}$. Arrow shows "flat liposome" in face- on position and arrow head shows "flat liposome in edge-on position. Bars = 200nm

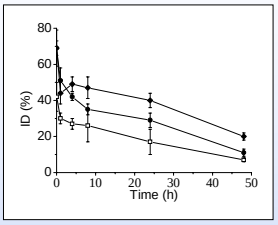


Fig. 5. Blood concentration vs. time curves of DPPC:Chol lipoliposomal formulatins following i.v. injection in rats: non-coated (open squares), coated with 5 mol % DSPE-PEG2000 (circles) and $(DDGG)_4(EO)_{114}$ (diamonds). Each data point represents the arithmetic mean ±S.D. (n=3)

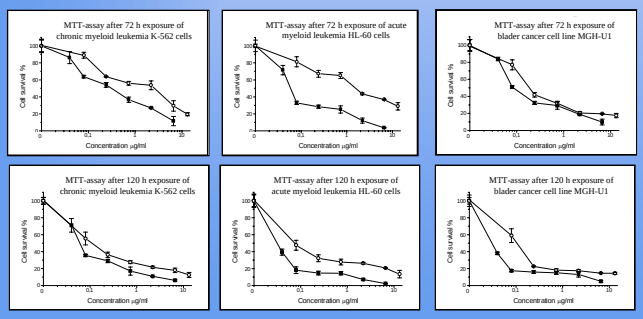
Table 2. Pharmacokinetic parameters of selected DPPC:Chol liposomes following in vivo application in Wistar rats

Parameter	Non coated	DSPE-PEG2000 (5 mol%)	$(DDGG)_4(EO)_{114}$ (5 mol%)
AUC_{0-48} (% dose.h/ml)	842,12	1336,42	1786,13
MRT (h)	31	31,8	43,9
Lz (h^{-1})	0,032	0,031	0,022
$T_{1/2}$ (h)	21,91	22,7	30,25
Vd (ml)	2,95	1,9	1,61
Cl p (ml/h)	0,09	0,058	0,037

Table 3. Organ distribution of liposomes 48 h after injection

Formulation	% of initial dose recovered at 48th h post-injection				
	Liver	Spleen	Liver + Spleen	Lung	Kidney
Non-coated	10 ± 3,3	6,0 ± 0,4	16,0 ± 3,0	0,3 ± 0,1	0,8 ± 0,0
DSPE-PEG2000	9,8 ± 2,9	3,7 ± 1,0	13,5 ± 0,0	0,4 ± 0,1	0,7 ± 0,1
$(DDGG)_4(EO)_{114}$	5,4 ± 3,2	4,8 ± 1,4	10,2 ± 4,0	0,5 ± 0,1	0,6 ± 0,1

Fig. 6. Cytotoxicity of free mitoxantrone (■) vs. liposomal in DPPC:Chol:(DDGG)4(EO)114 (○) against panel of human tumor cell lines.



CONCLUSION

✓ On the ground of our experimental results we can conclude that the present copolymers are promising candidates for steric stabilization of DPPC liposomes. We show that the copolymer condition the formation of DPPC liposomes, which are stable at physiological conditions. Exellent blood circulation time and abillity to avoid excessive accumulation in the RES organs were achieved with liposomes stabillized with copolymer bearing four lipid mimetic anchor.

✓ Liposomal mitoxantrone inhibited the growth of human malignant cells *in vitro*, whereby the dose-response curves where shifted to higher concentrations as compared to those of the free drug. This is an outcome of the sustained release of mitoxantrone from the liposomes.

✓ The increase of the exposure period is consistent with more pronounced cytotoxicity, especially in case of the liposomaly-entrapped drug. Actually 120 h post treatment the IC_{50} and IC_{80} end-point values of liposomal mitoxantrone were comparable or even lower than those of the free drug at the shorter treatment period (fig. 6).

Acknowledgements

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Operational program „Human resources development"
European Social Fund

NEW APPROACH FOR PREPARATION OF MEMBRANES FOR FUEL CELLS, COMPRISING POLYBENZIMIDAZOL WITH GRAFTED POLYVINYLPHOSPHONIC ACID CHAINS

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Summary

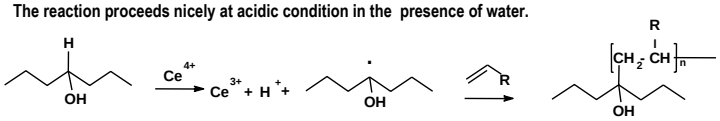
A new method for the preparation of polybenzimidazole (PBI) based membranes, containing very high concentrations of immobilized phosphonic acid groups, has been developed. The procedure used is carried out in two steps: 1) Preparation of films from modified PBIs, containing 1,2-hydroxypropyl groups 2) Introduction of vinylphosphonic acid (VPhA) and initiator (cerium ammonium nitrate) in the film, subsequent grafting of VPhA starting from the active sights on the PBI backbone. The procedure is very easy to perform – no specialized equipment is required. All materials used are commercially available. Membranes of big area and very good quality have been prepared.

Introduction

Membranes, containing covalently bonded phosphonic acid groups (-PO_3H_2), are expected to be able to transport protons at higher temperatures and lower humidity. The synthesis and properties of PEEKs with grafted polyvinylphosphonic acid chains, have been recently reported [1].
During the last years IP BAS and BASF Fuel Cell GmbH have jointly developed membranes, containing water insoluble -PO_3H_2 groups - polybenzimidazole containing cross-linked polyvinylphosphonic acid (EU Project Autobrane) and PBIs with grafted polyvinylphosphonic acid chains [2]. Here we present a new improved procedure for the preparation of such membranes.

Grafting of vinyl monomers

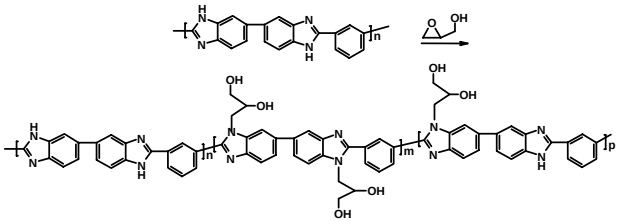
Selective generation of radicals on polymers, containing hydroxyalkyl groups (cellulose, starch, PVA) by oxidation with metal ions like Co^{3+}, Ce^{4+}, Mn^{3+}, V^{5+} and Fe^{3+}. Radical polymerization can be started from these active sites.
Advantages: Relatively low amount of homopolymer is formed during the reaction.
The reaction proceeds nicely at acidic condition in the presence of water.



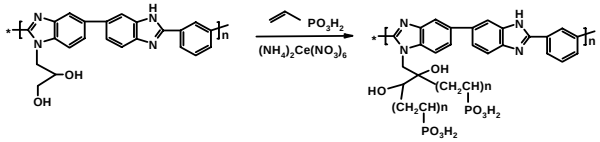
Our synthetic approach

Two-stage process:

Stage 1 – Synthesis of macroinitiators – modified PBIs, containing 1,2-hydroxypropyl groups



Stage 2 – Grafting of vinylphosphonic acid (VPhA) from the active sights



I. Synthesis of modified PBIs, containing –OH groups (macroinitiators)

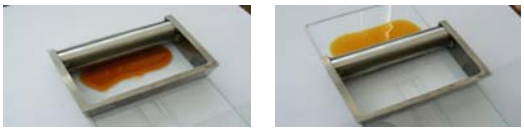
Starting material: Celasolve® - 15 wt.-% solution of PBI in dimethyl acetamide.
Synthetic procedure: N-alkylation with glycidol, basic catalyst (K_2CO_3), stirring for several hours (100 – 140°C).
Degree of modification (DM): substituents per PBI unit, determined from ^1H NMR data.
Example: 1 substituent per PBI unit – DM=50, 1 substituent per 5 PBI units – DM=10
Modified PBIs with DM = 3,10,20,40 have been prepared.

Acknowledgment:

D. B. thanks the Structural Funds and Educational Programs Directorate for financial support in the frame of the Project "Support for the development and realization of PhD-students, post-docs and young researchers in the field of polymer chemistry, physics and engineering", Grant № BG051PO001/07/3.3-02/51 51.

Preparation of thin films from modified PBIs

Procedure:
Casting a film from the reaction solution on a glass plate (doctor blade, gap 0.4-0.8 mm)
Drying in air, removing from the substrate, boiling in water
Smooth, homogeneous, flexible films, thickness: 30 - 80 μm



II. Preparation of membranes, consisting of PBI-graft-PVPhA

Objective: Starting from thin films of modified PBI to prepare membranes, consisting of PBI with grafted polyvinylphosphonic acid chains onto it.
A very easy and effective swelling procedure for introducing vinylphosphonic acid and initiator $(NH_4)_2Ce(NO_3)_6$ (CAN) has been developed.
First stage: Swelling in a bath containing VPhA and H_2O. The starting film increases its dimensions up to 100% and its weight up to 1500%.
Second stage: Introducing initiator in the swollen film obtained in the first stage.
Third stage: Grafting was performed in the swollen membrane by heat treatment.
Parameters varied:
- content of -OH groups in the starting PBI film (modified PBIs with DM=3-40 have been used)
- concentration of: monomer, co-solvent, initiator
- temperatures and time of swelling and grafting

Membranes of excellent quality have been prepared (Tab.1)

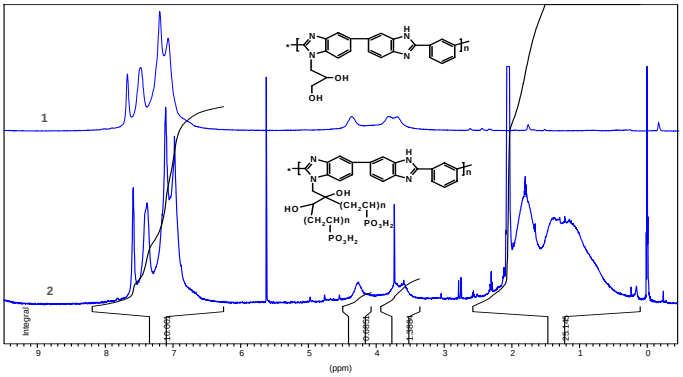
Tab.1 Membranes prepared

Starting material (Degree of modification)	Grafted membrane weight ratio PVPhA:PBI
PBI MGA5 (3%)	0,70:1 ÷ 1,80:1
PBI MGA8 (10%)	0,85:1 ÷ 2,30:1
PBI MGA9 (20%)	1,34:1 ÷ 2,75:1
PBI MGA7 (40%)	1,80:1 ÷ 3,60:1

Degree of grafting - determination

1. *Gravimetrically*-The membrane was thoroughly washed in water and dried. Weight uptake towards the weight of the starting film was calculated.
2. *From ^1H NMR data* – calculation of:
   - VPhA groups per PBI repeating unit
   - Weight uptake towards the weight of the starting film (weight ratio PBI/PVPhA)
   - Length of the grafted chains

^1H NMR spectra (H_2SO_4-d2, RT) of:
1) PBI MGA9 material, degree of modification - 20%
2) The same material with grafted polyvinylphosphonic acid chains



Conclusion:

It has been shown that VPhA can be grafted on modified PBIs containing OH groups. The membranes prepared contain considerable amount of water insoluble – PO_3H_3 groups (up to 10 mol VPhA per PBI unit). Proton conductivity is expected to exceed 10^{-2} S/cm.

References:

[1] J. Parvole, P.Jannasch *Macromolecules, 41* (11), 3893–3903, 2008
[2] Pat. Appl. DE 10 2006 057 655 A1 2006.08.14 Funktionalisierte Polyazole, Phosphonsaeregruppen aufweisende Polyazole, Polymembranen sowie Verfahren zur Herstellung, O.Uensal, J.Belack, K.Muellen, M.Klapper, V.Sinigersky, I.Schopov, St.Shenkov, Ch. Brachkov, S.Prabakaran, D.Markova

Polyelectrolyte Complex Based Nanofibers Prepared by Electrospinning

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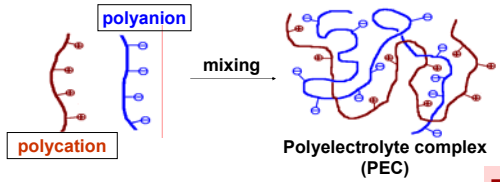
1113 Sofia, Bulgaria

Aim: **To find out suitable conditions (solvent system; absence/presence of a non-ionogenic electrospinnable polymer) for preparation of PEC based nanofibers by electrospinning.**



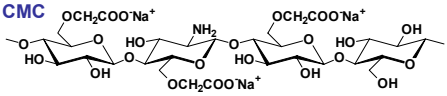
The mixing of aqueous solutions of oppositely charged polyelectrolytes leads to obtaining of a water-insoluble precipitate from the corresponding PEC. Thus, PEC based systems cannot be electrospun using H_2O as a solvent.

An appropriate solvent system consisting of $HCOOH/H_2O$ in presence/absence of low-molecular-weight salt ($CaCl_2$ or NaCl) allowing the preparation of PEC based nanofibers by electrospinning has been developed.

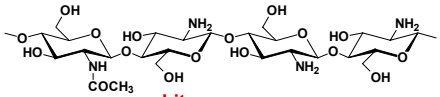
Polyelectrolyte pairs:

natural / natural [2]

CMC

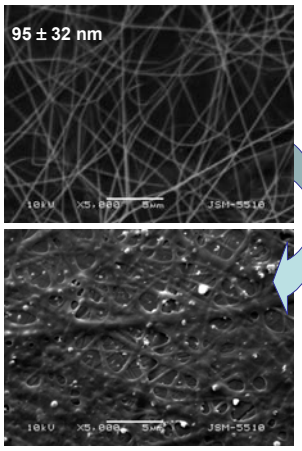


PAAm



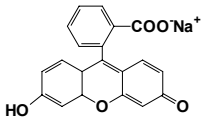
chitosan

The electrospinning of chitosan/CMC pair requires presence of a non-ionogenic electrospinnable polymer, such as PAAm

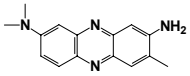


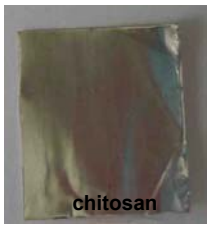
Staining with

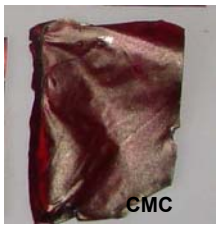
Fluorescein



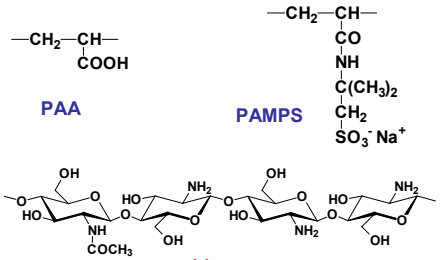
Neutral red



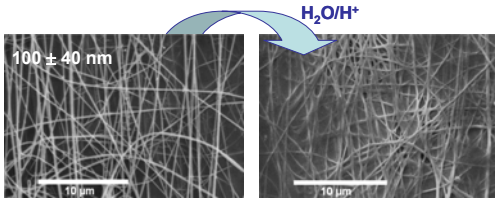




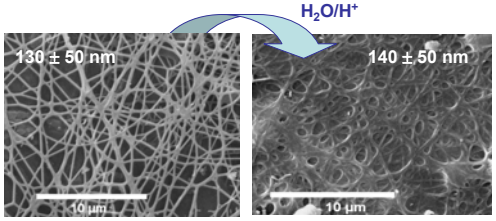
synthetic / natural [1]



The use of H_2O/HCOOH = 1/3.4 (v/v) as a solvent allows the electrospinning of **chitosan/PAA** pair.

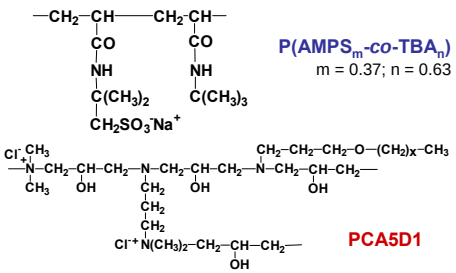


For **chitosan/PAMPS** pair the electrospinning is enabled by using H_2O/HCOOH = 1/6 (v/v) as a solvent and 2.5 wt.% $CaCl_2$.

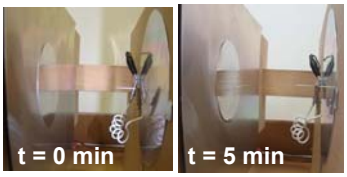


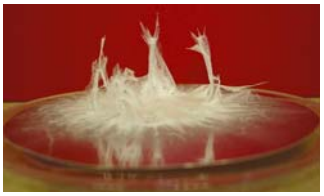
Yarns formation from self-assembled fibers during the electrospinning process from chitosan/PAMPS/ HCOOH/$CaCl_2$ system using a static collector [3]

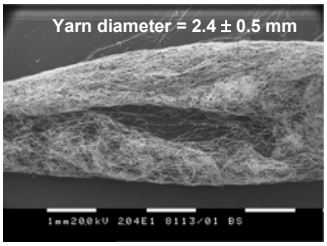
synthetic / synthetic [2]

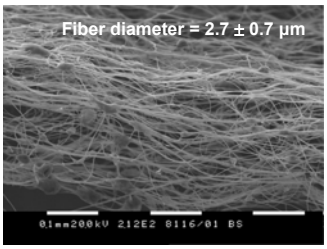


Yarns formation from self-assembled fibers during the electrospinning process from PCA5D1/P(AMPS-co-TBA)/HCOOH/ $CaCl_2$ system using a static collector









Conclusions: The one-step preparation of PEC based fibrous materials from natural and/or synthetic polyelectrolytes has been shown. These results are of significant importance for the design of new, pH-sensitive fibrous materials combining the beneficial properties of polyelectrolytes differing in nature. The prepared materials are potential candidates for diverse applications, including biomedical ones.

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STRUCTURE, RHEOLOGICAL AND ELECTRICAL PROPERTIES OF EPOXY/MWCNTs COMPOSITES

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INTRODUCTION

Carbon nanotubes (CNTs) represent a fast developing class of materials with a wide range of potentially interesting product applications related to areas such as mechanical, electrical and thermal property enhancement. In order to achieve optimal enhancement of the properties of CNTs/polymer composites, there are several key issues to be resolved, i.e., improved dispersion of CNTs, alignment of CNTs in the polymer resin, and functionalization of the CNTs surface for good adhesion. The key point of this work is to transfer the extraordinary properties of CNTs to the polymer nanocomposites. Epoxy-based composites containing various amounts of multiwall carbon nanotubes (MWCNTs) were prepared, and their performance was investigated. Effects of different dispersion states of CNTs in epoxy and polyethylene polyamine hardener (PEPA) on rheological properties of the nanodispersions were also studied. The composites exhibit a very low percolation threshold, in which a continuous electro-conductive network was formed.

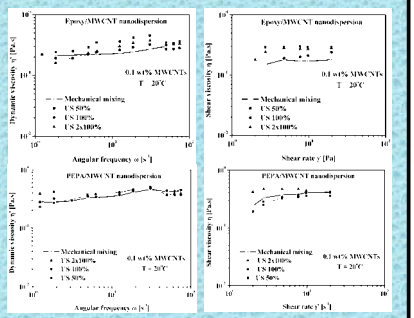
MATERIALS and METHODS

The nanocomposite matrix was based on D.E.R.™ 321 (ortho-cresyl glycidyl ether diluted standard bisphenol A based liquid epoxy resin), production of the Dow Chemical company. Polyethylene polyamine (PEPA) produced by the Bakelite Co. was used as a curing agent. MWCNTs with diameters between 10 and 40 nm, produced by the fast bed CVD method and containing about 8 wt% encapsulated ferromagnetic particles, were submitted by IFW Dresden. Sample homogenization was realized by high speed mechanical premixing and two steps of treatment using an ultrasonic cavitation disintegrator for nanoparticles with two stages of acoustic power, referred to further on as 50% and 100% ultrasonic treatment. Two different processing modes were applied. First, the MWCNTs were functionalized with amine groups by premixing with the amine hardener. Second, the MWCNTs were not functionalized with amine, as premixed with the epoxy oligomer. The studied concentration range varied from 0 to 0.1 wt%. The effect of mixing conditions (mechanical, ultrasonic) on the level of dispersion of nanocomposites was explored at 20°C by rheological methods using a cone-plate viscometer operating in an oscillatory and steady state mode. The influence of the MWCNTs content and the applied external magnetic field (EMF) on the electrical conductivity of the nanocomposites was also studied at room temperature by means of a Kethley 610C Electrometer.

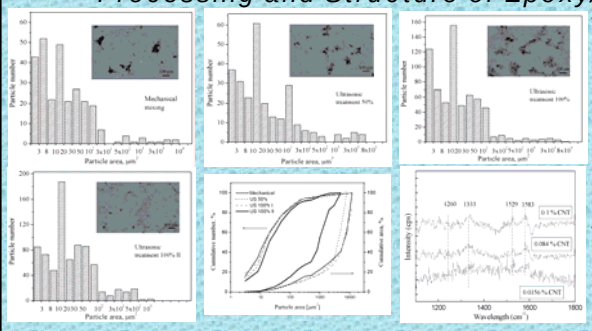
RESULTS and DISCUSSION

Rheological Properties of Epoxy/MWCNTs Nanocomposites

The rheological behaviour of the epoxy/MWCNT and PEPA/MWCNT compositions is close to the typically displayed by such systems Newtonian flow due to the relatively low nanofiller content (0.1 wt%). The values of the shear and dynamic viscosity exhibit good correspondence according to the Cox-Merz rule. The dynamic and shear viscosity values for epoxy/MWCNT dispersion shows that 50% ultrasonication leads to higher viscosity compared with other mixing steps. On the other hand nanodispersions with MWCNTs in the polyethylene polyamine hardener exhibit higher viscosity after the 4-th step of mixing (US 2×100%) where good homogenization is reached. These investigations were used for developing an optimal experimental protocol for the compositions, which were further on subjected to curing and studies of electrical properties and structure. The viscometric results are in agreement with optical (POM) observations, which show that in some cases the further ultrasonic treatment leads to an enhancement of the reaggregation processes in the compositions.



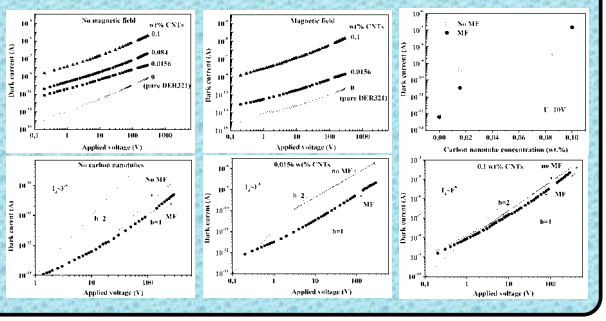
Processing and Structure of Epoxy/MWCNTs Nanocomposites



The first intensive ultrasonic treatment (US2 I) of MWCNT in PEPA results in better homogenization and the second one after 24 h (US2 II) yields the best results. The cumulative number distribution shows that in all cases the prevalent number of aggregates (>80%) are with an area less than 100 μm² (per particle). As seen, the total particle area corresponding to 80% of the particles is less than 10%. The second intensive treatment after 24 h yields reduced dimensions of the particles and more loose structure of aggregates. This is confirmed also by the rheological experiments (higher viscosity of the suspensions due to better dispersion) and by the measurement of the current-voltage characteristics (probable more expressed formation of percolation conductive pathways). The results indicate that the electric current sharply rises with more than 2 decades at concentration of 0.0156 wt%, exhibiting behaviour close to the percolation threshold. The character of the Raman spectra of the composites resembles that of the pristine polymer with some effects in the intensity due to the presence of carbon nanotubes.

Electrical Properties of Epoxy/MWCNTs Nanocomposites

It is seen that a very low concentration of nanotubes (0.0156 wt%) leads to significant enhancement (more than two decades) of the composite conductivity compared to the pristine polymer. A sharp rise is observed at 0.1 wt%, which is indicative of the percolation occurrence. Further studies will be performed to determine the exact values of the rheological and electrical percolation thresholds. Two ranges are distinguished in the I-V characteristics shown. At low voltages (up to 2x10² V/cm) a linear Ohmic region is observed, followed by a superlinear region at higher voltages. These results indicate transition from Ohmic conductivity at low applied fields to a different conductivity mechanism at higher fields. It is also seen that the applied external magnetic field has no substantial effect on the electrical conductivity of the samples within the studied low concentration range.



Conclusions. **(1) The effect of processing on carbon nanotube dispersion in epoxy matrix shows that chemical functionalization is the most important factor for the homogenization of composites. The rheological properties of the PEPA/MWCNT dispersions prove that the most optimal homogenization of carbon nanotubes is achieved in the amine hardener after the second stage of intensive ultrasonic treatment. (2) The character of the Raman spectra of the composites resembles that of the pristine polymer with some effects in the intensity due to the carbon nanotubes. The spectra confirm better exfoliation of nanotubes in amine hardener than in epoxy resin. (3) The applied processing protocol has enhanced the achievement of a percolation threshold in electric conductivity at a very low carbon nanotube concentration between 0.0156 and 0.084 wt%. The effect of the applied external magnetic field is not pronouncedly observed in the electric conductivity and Raman spectroscopy studies due to the very low MWCNT concentration.**

Acknowledgment: **The study is supported by several projects: BG051PO001/07/3.3-02/51, NSF-Bulgaria, 2008; D01-469/06 and D002-53/08, NSF-Bulgaria and FP7-CSA-NaPolyNet (2008-2011). We acknowledge our gratitude to IFW Dresden for the supply of MWCNT.**

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Grafting of Polyacrylamide and Poly(N-isopropylacrylamide onto Carbon Nanotubes via UV irradiation. Preparation of macroporous nanocomposites.

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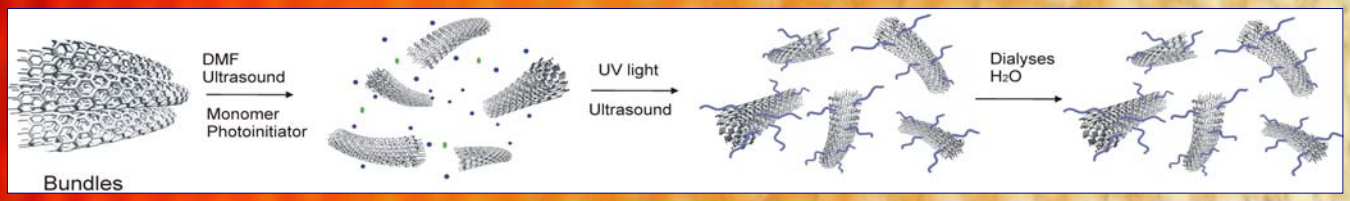
Introduction

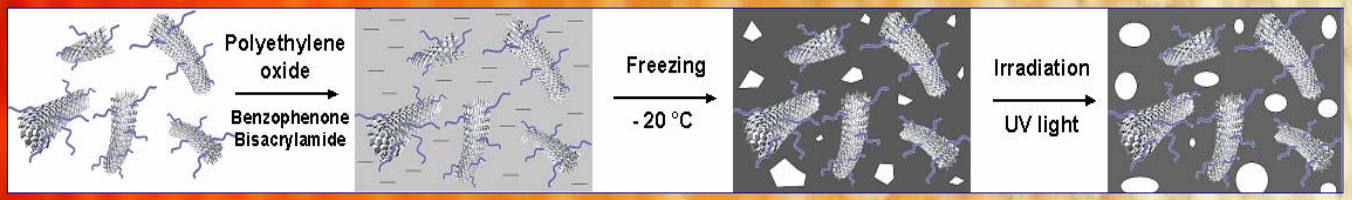
Pristine carbon nanotubes (CNTs) interact mutually by van der Waals forces which makes difficult their dispersibility in liquids and processing. Grafting of polymer chains onto CNTs is a straightforward strategy for preparation of homogenous dispersions of CNTs in water and N,N-dimethylformamide as well as polymer melts. Water-soluble carbon nanotubes are of special interest because of possible biochemical and biomedical applications.

Strategy

1. Grafting of polymers onto MWNTs via UV-induced free radical polymerization



2. Preparation of macroporous nanocomposites of very low percolation threshold of MWNTs

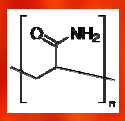


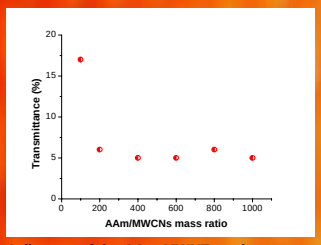
Results

Multi-walled carbon nanotubes: produced by the CVD method (carbon content>95%; OD×ID×L:20-30nm × 5-10nm × 0.5-200 μm)

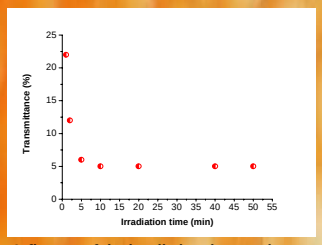
1a. Grafting

Polyacrylamide



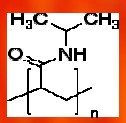


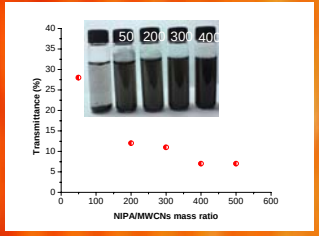
Influence of the AAm:MWNTs ratio on the grafting efficiency at 10 min irradiation with UV light



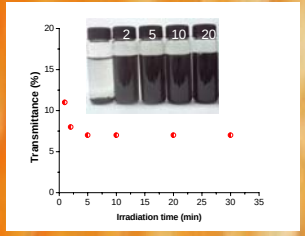
Influence of the irradiation time on the grafting efficiency at AAm:MWNTs mass ratio 400:1

Poly(N-isopropylacrylamide)

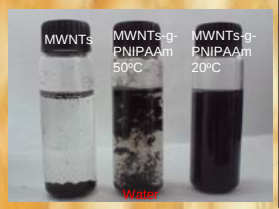




Influence of the NIPAAm:MWNTs ratio on the grafting efficiency at 10 min irradiation with UV light



Influence of the irradiation time on the grafting efficiency at NIPAAm:MWNTs mass ratio 400:1

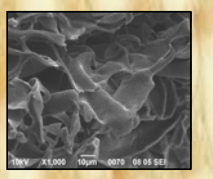


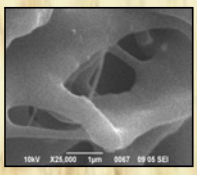
Sample composition	Initial ratio w/w	Irradiation time min.	Grafted polymer/MWCNT's* w/w
AAm/MWCNT's	400:1	2	1:5,8
AAm/MWCNT's	400:1	10	1:4,6
AAm/MWCNT's	400:1	40	1:4,2
NIPAAm/MWCNT's	400:1	2	1:4
NIPAAm/MWCNT's	400:1	10	1:2,8
NIPAAm/MWCNT's	400:1	30	1:2

**data from TGA analysis*

Preparation of macroporous PAAm/MWNTs nanocomposites by cryo-structuring of aqueous systems and freeze drying:

Macroporous nanocomposites are obtained by mixing high molecular weight PEO with PAAm-grafted MWNTs in aqueous media, freezing at minus 20 °C and subsequent freeze drying.





Scanning electron microscopy images of PAAm/MWNTs macroporous nanocomposites at different magnifications

Acknowledgement: This research work was supported by Bulgarian Ministry of Education and Science, Structural Funds and Educational Programs Directorate, Project "Support for the development and realization of PhD-students, post-docs and young researchers in the field of polymer chemistry, physics and engineering", **Grant 51**, **financed by the Operational Program "Human resources development" at the scheme BG051PO001/07/3.3-02.**

MECHANICAL PROPERTIES AND MORPHOLOGY OF TOUGHED POLYETHYLENE/POLYPROPILENE BLENDS

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I. INTRODUCTION

Polyethylene (PE) and polypropylene (PP) form considerable part of the ever-increasing stream of plastic wastes. As the gravimetrical separation of PE/PP mixed wastes is impossible due to the similarity of their density, investigation of their common processing is very important.

PE and PP are known as thermodynamically incompatible, which reduces the mechanical properties of their blends [1]. Compatibilization is an outstanding way of allowing polymers with poor compatibility or none at all to be melted with one another to form a useful combination of properties [2].

The purpose of this paper is to study the influence of the composition and structure of LDPE/PP blends toughed by two types of elastomers: non polar ethylene propylene rubber (EPR) and polar nitrile butadiene rubber (NBR) on their mechanical properties.

II. EXPERIMENTAL

Double and triple polymer blends mixed in a sesqui-screw extruder at a high shear rate were investigated. Double blends of low density polyethylene (LDPE) "ROPOTEN", MSR = 0.8g/10min (Bulgaria) and polypropylene (PP) "BUPLENE 6631", MSR = 2g/10 min (Bulgaria) at ratio 1:1 were used [3]. The both elastomers EPR and NBR were adding in concentrations from 7 wt % to 15 wt% to the PE/PP blend (1:1) used as a starting polymer.

The secondary polymers were blended in a twin-screw extruder type DSE 35/17D Plastograph Plasti-Conder "BRABENDER" OHG DUISBURG at 10 hvm,at temperature - 210oC and high shear rate.

Were investigeted tensile strength and elongation (EN ISO 527) and Charpy impact strength (EN ISO 179). Morphology of composites was studied by Scanning Electron Microscopy (SEM) on JEOL instrument. Degree of crystallinity and the relative size of crystallites were determined by using X-ray diffraction method (XRD). All data were collected by using TuR-M-62 diffractometer (Germany) coupled to a copper rotating anode X-ray source. [4].

III. RESULTS AND DISCUSSION

Results for the basic mechanical properties of the di- and three-constituents composites obtained are shown in Fig. 1 and Fig. 2.

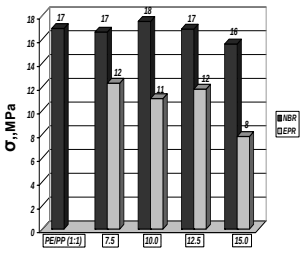

Fig. 1. Tensile strength of NBR- (black bars) and EPR-containing (grey bars) blends

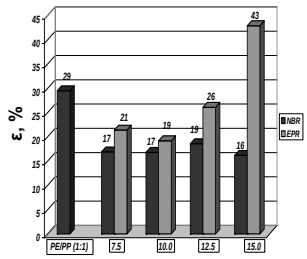

Fig. 2. Elongation of NBR- (black bars) and EPR-containing (grey bars) blends

Results from tensile tests of triple blends containing NBR in the interval of concentrations to 15 per cent show that the rubber practically does not effect on the tensile strength of PE/PP blends (Fig. 1) and reduces elongation of the double blends from 37 to 45 per cent (Fig. 2). At the same time decrease in the strength under the influence of the unpolar rubber is more than twice at the highest per cent (15%) of EPR and the reduction is proportional to the increase of its concentration. As well, after a small reduction of the elongation at the lower concentrations of EPR its further addition strongly increases the elongation at concentration of 15%.

Very similar results are obtained in testing the impact strengths of the double and triple blends (Fig. 3). No significant changes are established in the strengths of the triple blends when NBR is used.

Completely different picture is seen at the triple blends containing EPR. Significant improvement in the impact strength of the triple comparing with double blends is established which increases with enhancement of the rubber content.

In general, the availability of elastomer in the blends reduces their crystallinity. Increase in the amount of amorphous phase with the increase of the elastomer content is established. The trends are graphically expressed in Fig. 4.

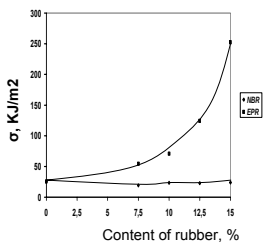

Fig.3. Charpy impact strength (σ) of PE/PP blends (1:1) with different content of rubber

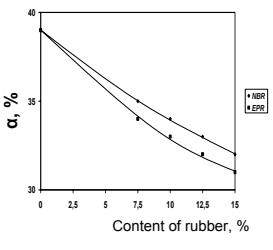

Fig. 4. Influence of the content of rubber on the degree of cristalinity (α) of the blends

The rubber type and concentrations affect also the crystallites sizes (Table 1). Trends of enhancement of the maximum widths, corresponding to reduction of the crystallites size with the increase of concentrations of both elastomers, are noticed.

Table 1. Influence of the elastomer type and concentration on the width at the semi-height of the main diffraction maximum

No	Rubber concentrations, wt. %	NBR-40		EPR	
		PP	LDPE	PP	LDPE
1.	0	7.0	9.0	7.0	9.0
2.	7.5	6.0	9.0	6.5	8.0
3.	10.0	6.0	9.0	8.0	9.0
4.	12.5	7.0	10.0	9.0	10.0
5.	15.0	9.0	9.0	8.0	10.0

Morphology of the blends was examined by SEM (Fig. 5). The picture 5a shows phase separation of the individual components. Obviously there is insufficient interdiffusion of PE and PP. Partial binding of the separated phases by formation of bridges is established at the triple blends containing NBR.

It is well observed, that the size of domains in the blend, containing 12.5 % NBR is in the range of 3 μm to 10 μm, which size is considered to ensure the best possible impact strength for the corresponding blends [5]. As could be seen in Fig 5c in the blend, containing 12.5% EPR the domains are with smaller size - 2 - 3 μm, comparing to the corresponding NBR-containing triple blends. As a difference with the NBR-containing blends in this case the formed rubber domains are difficult to be distinguished which apparently is a sign for a significantly better compatibilisation of the blended PE and PP.

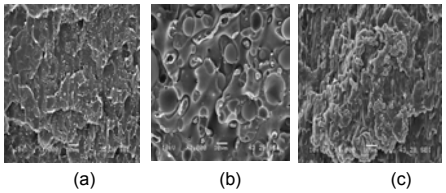

Fig. 5. SEM morphology (x1000) of (a) cryogenic fractured surface of LDPE/PP blend (1:1); (b) triple LDPE/PP (1:1) blend containing 12.5% NBR and (c) triple LDPE/PP (1:1) blend containing 12.5% EPR

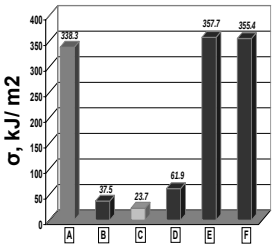

Fig. 6. Charpy impact strength of blended recyclates: [A] -LDPE-recyclate; [B] –PP- recyclate; [C] – LDPE/PP(1:1) –recyclates; [D] – LDPE/PP(1:1) – virgin polymers; [E] – LDPE/PP(1:1)-EPR(15%) – recyclates; [F] – LDPE/PP(1:1)-EPR(20%) – recyclates

Initial experiment for blending secondary polymers was carried out by using twin-screw extruder in presence or without 15 and 20 per cent EPR. The impact strength of double and triple blends of recyclates, compared with the single ones are shown in Fig. 6. As could be seen the strength of PE/PP blend of recyclates is strongly reduced much less than the strength of the single recyclates or this of the virgin polymer blend. When the blend is compatilized by EPR the strength rises even more than this of LDPE which probably is result of the influence of rubber on the accelerated relaxation processes in the triple blends

IV. CONCLUSION

The results obtained confirm that when the unpolar EPR in concentrations 12-15 per cent is blended at high shear rate with the incompatible olefins - LDPE and PP, composites with high impact strength are obtained. The addision of NBR doesn't affect of the tensile and impact strenght. This is due to significantly better compatibilisation of the blended PE and PP with EPR and the influence of the EPR on the structure and accelerated relaxation in the triple blends. This supplies an opportunity for utilisation of mixed foil wastes from LDPE and PP with good properties for specific purposes.

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Novel Promising Biologically Active Polymers and Drug Carriers. Design and NMR Characterization

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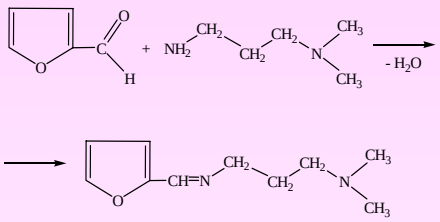
Introduction

The discovery of the ability of macromolecules to localize to subcellular compartments known as lysosomes heralded their evolution as drugs or drugs carriers [1]. The macromolecular approach to improve some characteristics of widely used low-molecular mass bioactive compounds enables the formation of unique types of therapeutics. The properties of the polymer are directly responsible for defining the circulation half life, rate of cellular uptake, minimizing toxicity of potent cytotoxic drugs, and impart favourable physicochemical properties. The use of biocompatible polymers as drug carriers is a well-known and widely studied approach [2-3]. Among the numerous macromolecular systems potentially viable as drug delivery vehicles the polymers with phosphor-diester (C-O-P-O-C) repeating units in the backbone are particularly interesting because of their biocompatibility and structural resemblance to natural biomacromolecules like nucleic acids [4]. Poly(alkylene H-phosphonate)s are a relatively new family of biodegradable polymers that are being actively investigated for pharmaceutical application such as polymer carriers of drugs [5]. and , genes [6].

Aminophosphonic acids constitute an important class of biologically active compounds, which are effective in suppressing herpes viruses, tumor growth, rhinoviruses, etc [7]. Aminophosphonic acids bearing furan moiety combine two pharmacophoric groups in the same molecule and seem to be very promising for application in medicine and pharmacy [8].

Synthetic Route

N,N-Dimethyl-N'-furfurylidene-1,3-diaminopropane



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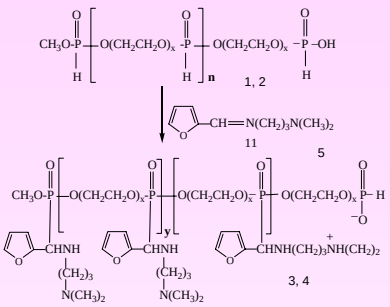
Poly(oxyethylene aminophosphonate)



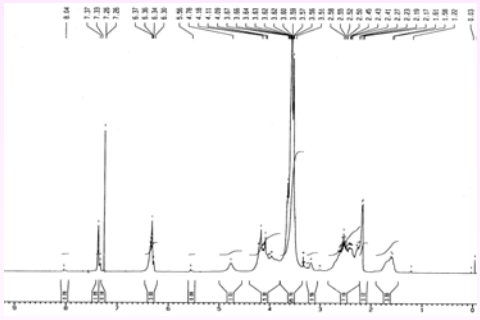
1, 2 – x = 4 PEG 200
3, 4 – x = 13 PEG 600

Reaction conditions for the preparation of poly(oxyethylene aminophosphonate)s

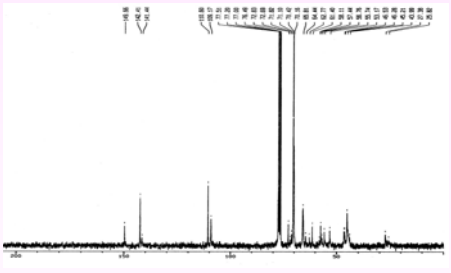
Schiff base, mol	POEPH, mol	Catalyst, mol	Reaction temperature, °C	Reaction time, h	Yield, %
0.017	0.017*	-	65	15	90
0.022	0.022*	CdI_2 (2.8×10^{-4})	50	3	92
0.062	0.062**	CdI_2 (1.2×10^{-4})	50	3	91

* - POEPH – poly(oxyethylene H-phosphonate) based on PEG -200;
** - POEPH – poly(oxyethylene H-phosphonate) based on PEG -600;

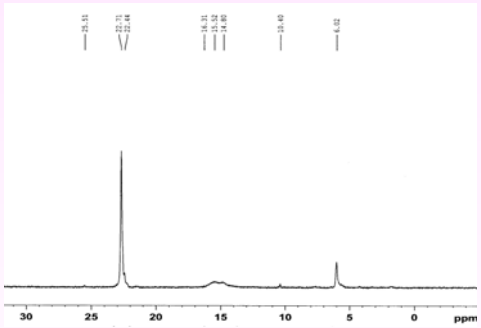
Analyses



^1H NMR spectrum of the Poly(oxyethyleneaminophosphonate)



^{13}C NMR spectrum of the Poly(oxyethyleneaminophosphonate)



^{31}P NMR spectrum of the Poly(oxyethyleneaminophosphonate)

Possible Application

The main goal of this study is exploring the polymer analogous reaction between poly(oxyethylene H-phosphonate) and Schiff base bearing furan moiety to be synthesized for the first time poly(oxyethylene aminophosphonate)s. These polymers are interesting as polymer drug carriers and as polymers with own bioactivity.

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Conclusions

- A novel poly(oxyethylene aminophosphonate)s were obtained for the first time in high yield via additional polymer analogous reaction between poly(oxyethylene H-phosphonate)s and N,N-Dimethyl-N'-furfurylidene-1,3-diaminopropane (Schiff base).
- The presence in the repeating unit of three coordination centres- the oxygen atom of the P=O group, and the two nitrogen atoms of the amino groups- makes them attractive and promising polymers for physical immobilization of biologically active substances.
- The new functional group- amino group- determines various chemical transformations of these polymers.

Acknowledgments: We thank to the Structural Funds and Educational Programs Directorate, Grant "BG051PO001/07/3.3-02/51" for the financial support. Bulgaria, Sofia, 2009

Anionic Poly(ε-caprolactam-co-ε-caprolactone) and Poly(ε-caprolactam-co-δ-valerolactone) Copolymers: Properties and Structure

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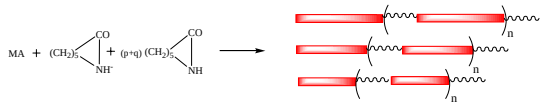
[2] Centre of Education and Research on Macromolecules (CERM), University of Liege (Belgium)
e-mail: natally_toncheva@yahoo.com, rpm@uctm.edu, rjerome@ulg.ac.be

Goal :

Investigation of the properties and structures of originally synthesised biodegradable poly [(ε-caprolactam)-co-(ε-caprolactone)] P[(CLA)-co-(CLO)] and poly [(ε-caprolactam)-co-(δ-valerolactone)] P[(CLA)-co-(VLO)] copolymers.

: Synthesis

Anionic polymerization of caprolactam (CLA) initiated by Na-Cl in the presence of polymeric activators (PACs) synthesized on the base of diisocyanate functionalized polylactone oligomers.



: Properties and Structure

The specific role of the new PACs used on the chemical and physical behavior were studied by DSC, HiRes TGA, DMTA, XRD, OM and TEM, notched impact and tensile strength and water absorption.

Copolymers :

Varying the type, concentration and molecular weight of the PACs a large diversity of copolymers were prepared.*

Table 2

№	Copolymers composition wt. %	DSC T'_g (°C)	DSC T'_m (°C)	DSC T'_m (°C)	DSC α''_{DSC} (%)	HiRes TGA $T_{d5\%}$ (°C)	HiRes TGA T_{dmax} (°C)	XRD α_{XRD_1} (%)	XRD $\alpha_{XRD\perp}$ (%)
1.	$(PCLA)_{100}$	53,2	221,4	218,2	25,2	384	396	42,50	39,00
2.	$(CLA)_{98}(MA_{PCLO550IF})_2$	52,8	220,9	-	-	197	392	45,92	39,80
3.	$(CLA)_{95}(MA_{PCLO550IF})_5$	52,7	221,0	-	-	215	389	43,72	38,85
4.	$(CLA)_{90}(MA_{PCLO550IF})_{10}$	49,3	217.3	-	-	290	386	38,72	34,40
5.	$(CLA)_{98}(MA_{PCLO1250IF})_2$	52,5	218,6	215,9	21,98	384	388	41,80	39,61
6	$(CLA)_{95}(MA_{PCLO1250IF})_5$	49,2	218,4	215,8	21,65	356	383	40,06	35,10
7.	$(CLA)_{90}(MA_{PCLO1250IF})_{10}$	45,1	217,1	214,9	20,66	295	384	37,77	33,25
8.	$(CLA)_{98}(MA_{PCLO2000IF})_2$	52,2	218,4	215,7	20,72	389	398	42,40	36,11
9.	$(CLA)_{95}(MA_{PCLO2000IF})_5$	48,6	217,5	214,7	21,44	368	384	41,04	35,05
10.	$(CLA)_{90}(MA_{PCLO2000IF})_{10}$	39,1	216,8	213,5	21,65	307	379	29,92	25,89
11.	$(CLA)_{98}(MA_{PCLO3000IF})_2$	48,5	217,4	215,6	20,43	385	392	40,35	36,05
12.	$(CLA)_{95}(MA_{PCLO3000IF})_5$	46,3	216,3	214,9	20,00	370	388	39,81	35,01
13.	$(CLA)_{90}(MA_{PCLO3000IF})_{10}$	38,3	216,0	213,8	21,11	315	374	28,90	24,06
14.	$(CLA)_{98}(MA_{PVLO3200IF})_2$	50,4	217,7	216,3	19,95	357	373	38,10	40,50
15.	$(CLA)_{95}(MA_{PVLO3200IF})_5$	47,1	215,0	214,7	19,78	314	374	35,60	37,80
16.	$(CLA)_{90}(MA_{PVLO3200IF})_{10}$	34,9	213,7	213,3	19,26	287	370	28,60	22,80

DSC curves

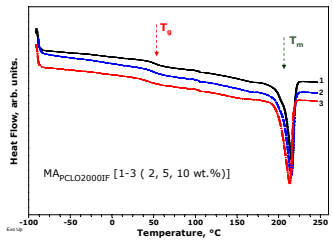
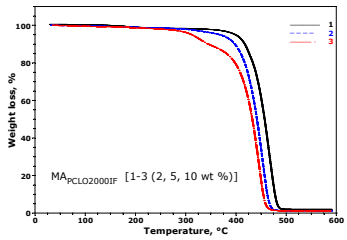


Table 1

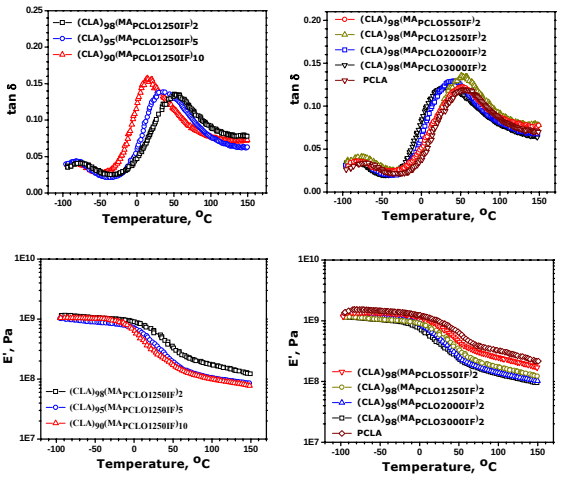
№	Codes of MA used	Copolymers composition, wt. %	Copolymer Yield (%)
1.	$MA_{PCLO550IF}$	$(CLA)_{98}(MA_{PCLO550IF})_2$	99.00
2.		$(CLA)_{95}(MA_{PCLO550IF})_5$	98.56
3.		$(CLA)_{90}(MA_{PCLO550IF})_{10}$	93.68
4.	$MA_{PCLO1250IF}$	$(CLA)_{98}(MA_{PCLO1250IF})_2$	97.58
5.		$(CLA)_{95}(MA_{PCLO1250IF})_5$	97.54
6.		$(CLA)_{90}(MA_{PCLO1250IF})_{10}$	91.38
7.	$MA_{PCLO2000IF}$	$(CLA)_{98}(MA_{PCLO2000IF})_2$	99.43
8.		$(CLA)_{95}(MA_{PCLO2000IF})_5$	96.60
9.		$(CLA)_{90}(MA_{PCLO2000IF})_{10}$	93.88
10.	$MA_{PCLO3000IF}$	$(CLA)_{98}(MA_{PCLO3000IF})_2$	99.81
11.		$(CLA)_{95}(MA_{PCLO3000IF})_5$	99.43
12.		$(CLA)_{90}(MA_{PCLO3000IF})_{10}$	93.40
13.	$MA_{PVLO3200IF}$	$(CLA)_{98}(MA_{PVLO3200IF})_2$	99.80
14.		$(CLA)_{95}(MA_{PVLO3200IF})_5$	96.72
15.		$(CLA)_{90}(MA_{PVLO3200IF})_{10}$	92.00

TGA curves

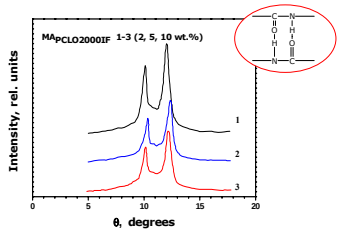


Destruction energy of the isolated bonds:C-C=345 kJ.mol^{-1}, C-O=357 kJ.mol^{-1}, C=O = 745 kJ.mol^{-1}, C-N=304 kJ.mol^{-1}, C-H= 413 kJ.mol^{-1}, N-H= 391 kJ.mol^{-1}

DMTA curves



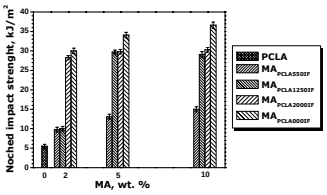
XRD curves



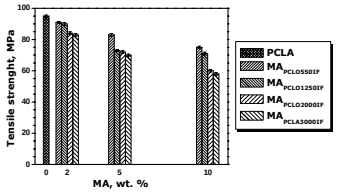
α - monoclinic modification, with two main reflexes : α_1 observed at scattering angle θ=10° and α_2 observed at scattering angle θ=12°.

: Mechanical tests :

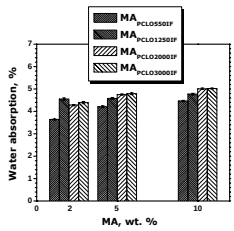
: Notched Impact strength



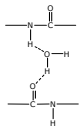
: Tensile strength



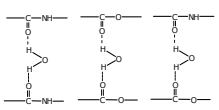
: Water absorption :



Hydrogen bonded water

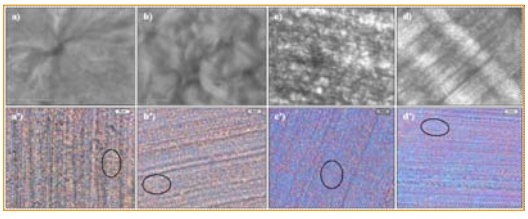


Associated water



PCLA water absorption (8÷10) %

: OM and TEM micrograms :



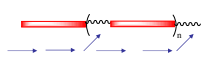
a) and a') MAPCLO550IF; b) and b') MAPCLO1250IF; c) and c') MAPCLO2000IF; d) and d') MAPCLO3000IF [5 wt. %]

$MA_{PCLO2000IF}$: a) 2 wt. %; b) 5 wt. %; c) 10 wt. %.

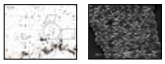
: Future outlook :

Biodegradation

Rhizopus arrhizus Lipase (EC 3.1.1.3.)



Biofilm Formation



Arthrobacter, Pseudomonas, Trichosporon

Ability to remove pollutants from aqueous solutions

Summary :

- The synthesized copolymers are semicrystalline.
- The DSC curves showed always single melting endotherms in the melting region of PCLA.
- Polylactone segments, incorporated into the PCLA main chains are mainly located in the amorphous region and that the copolymers with partially blocky to random structure are formed.
- With increasing the PACs concentration in the copolymers the changes in thermostability are negligible.
- The apparent lack of two α-transitions (resp. two Tg) unambiguously proves that each segment of the amorphous phase in copolymers is compatible in molecule scale (microphase separation does not occur). .
- Incorporation of PCLO or PVLO into PCLA main chain lead to an improvement of the notched impact strength and water absorption without significant changes in the tensile strength, elastic modulus and elongation at break, for all copolymers in comparison to the PCLA.

Funding:

Operational Program "Human resources development" – BG051PO001/07/3.3-02 under project "Support for the development and realization of PhD-students, post-docs and young researchers in the field of polymer chemistry, physics and engineering".

*Chromcova, D., Baslerova, L., Roda, J., Brozec, J.,European Polymer Journal 44 (**2008**) 1733.

ELECTROSPUN NANOFIBROUS MEMBRANES TAILORED FOR ACETYLCHOLINESTERASE IMMOBILIZATION

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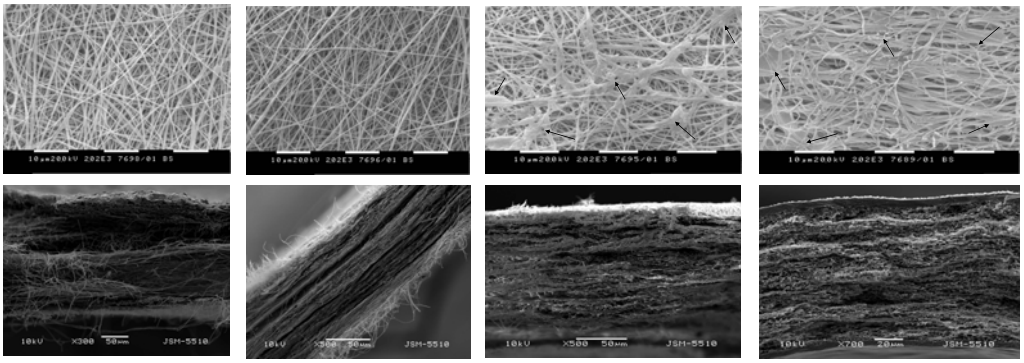
Aim Electrospinning is a cutting edge technique that allows producing continuous polymer fibers with submicron diameters. Because of their inherent large specific surface area and the small pore size, the electrospun materials have a great potential as supports for enzyme immobilization. Therefore, the aim of the work is to prepare nanofibrous polyacrylonitrile membranes by electrospinning and further to tailor membranes for acetylcholinesterase immobilization, resulting in promising material for biocatalysts.

Preparation and modification of nanofibrous PAN membranes

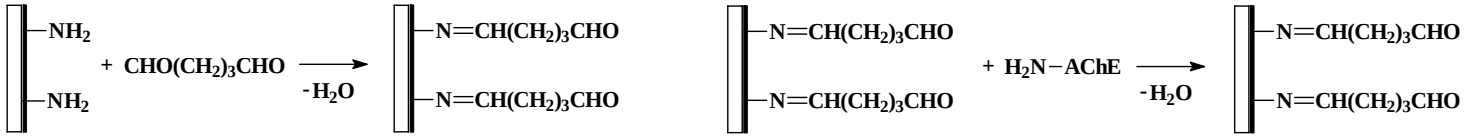
Nanofibrous PAN membranes (PANNFM) were fabricated by electrospinning. At first, the PAN solution (17 wt% in DMF) was electrospun directly onto the aluminum collector fixed onto a home-made rotating drum (1) at 20 kV. The flow rate was 1.1 ml/h and the spinneret diameter was 0.4 mm (5). The distance between the collector and the spinneret was 6 cm. In the electrospinning setup, a rotating drum with the diameter of 9 cm and a rotating speed of 1100 rpm was used to collect the deposited PAN nanofibers. In this way, uniform electrospun PANNFM with area 15×20 cm^2 were prepared. On the next stage, as-spun PANNFM was modified consecutively with NaOH and EDA. Finally, the membranes were modified with chitosan with low and high molecular weight. These membranes will be further denoted as PANNFM/CHI-L and PANNFM/CHI-H, respectively.



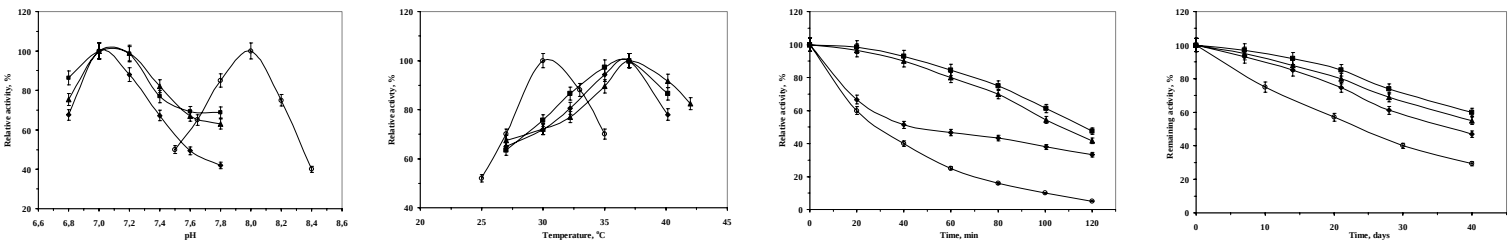
Membranes preserved their uniform fibrous surface morphology. The modification with chitosan alters the surface morphology of the membranes - a thin film of chitosan is observed between the fibers; this is additional evidence that modification has occurred. The corresponding cross-sectional SEM show that all prepared membranes exhibit a multilayer structure. The porous surface of the membranes suggests that adsorption of the enzyme will take place not only on the outer surface but also on the interior by diffusion into the pores.

Immobilization of acetylcholinesterase

In order to immobilize covalently AChE, the amino groups of PANNF/CHI membranes were initially activated by glutaraldehyde as coupling agent, followed by reacting with enzyme-containing solution for conjugation with the amino groups of AChE. It was shown by us that the proposed method is a simple and effective for covalent immobilization of enzymes to inert PAN membranes. Moreover, the immobilized enzymes showed good stability and reusability.



On the positively charged PANNF/CHI membranes, the optimum pH was shifted to lower pH values. The immobilized AChE showed an optimum temperature at about 37ºC, whereas free AChE had an optimum temperature at 30ºC. Therefore, the thermal stability of AChE could be enhanced by the immobilization on an appropriate support. It was found that the enzyme bound on PANNF/CHI-L and PANNF/CHI-H membranes was more stable with time (about 50% of the enzyme activity was lost for 120 min) than immobilized on PANNF/NaOH/EDA membranes (approximately 30% of the enzyme activity was lost for 120 min), while for this time the free AChE was almost inactivated. The activity of immobilized AChE was much higher in the first 20 days – 75%, 80% and 85% for PANNF/NaOH/EDA, PANNF/CHI-H and PANNF/CHI-L membranes, respectively. Hence, the maximum storage stability was observed for AChE immobilized on PANNF/CHI-L membrane, which retained about 60% at the end.



After enzyme immobilization, the storage stability was substantially improved compared to that of free AChE. Therefore, the herein prepared nanofibrous PAN membranes are promising supports in the AChE immobilization.

Acknowledgements: O.S. thanks the European Social Fund, Structural Funds, Operational Programme "Human Resources Development" for financial support in the frame of Grant No. BG051PO001/07/3.3-02/51. Financial support from the National Science Fund (Grant TC-Ch-1605) are gratefully acknowledged.

Synthesis and investigation of antibacterial properties of copolyelectrolytes based on poly(vinyl alcohol)

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Introduction

Grafting is one of the techniques employed for modifying the chemical and physical properties of a polymer. Polyvinyl alcohol (PVA) is the world's largest volume synthetic, water-soluble polymer. It is used in various types of applications because of its excellent physical properties. PVA is a known biomedical polymer. Due to its biocompatibility, PVA can be used for a variety of biomedical applications such as wound dressing, coatings for implantable devices, protein delivery systems, etc., mainly in the form of hydrogels [1, 2]. PVA is a reactive polymer containing one hydroxyl group in every repeating unit which gives possibility for different modification, grafting and coupling reactions to be performed. The ceric ion mediated polymerization method is interesting methods to graft vinyl monomers on polymers possessing oxidizable functional groups. The advantages of this grafting reaction are mild reaction conditions and use of the ecologically preferable aqueous reaction media.

During the last two decades there have been increasing efforts in the synthesize of antibacterial polymers due to their application as coatings in many areas, including food processing, biomedical devices, for filters etc. [3]. These polymers can be used in paints on hospital-room walls and everyday objects such as doorknobs, children's toys, computer keyboards, and telephones. In general, the development of novel antibacterial polymers aims at improved antibacterial activity, reduced residual toxicity, increased efficiency and selectivity, and prolonged lifetime.

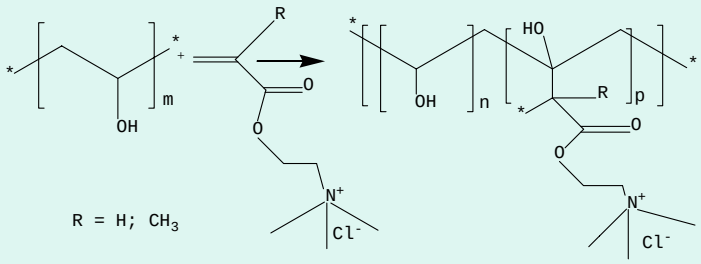
Objectives

The aim of this work is to synthesize series of flexible copolyelectrolytes by grafting charged cationic monomers [2-(methacryloyloxy)ethyl]-trimethylammonium chloride (METMAC) and [2-(acryloyloxy)ethyl]-trimethylammonium chloride (AETMAC) on PVA of different chain length and to investigate there antibacterial activity.

Results and discussions

A series of novel polyelectrolyte has been synthesized by grafting of mono-charged cationic monomers on PVA of different molar mass (10 000 g/mol and 49 000 g/mol) by applying cerium mediated polymerization in aqueous solution at 35°C. The cationic monomeres used for grafting were the [2-(acryloyloxy)ethyl]-trimethylammonium chloride (AETMAC) and [2-(methacryloyloxy)ethyl]-trimethylammonium chloride (METMAC). The optimal reaction conditions for grafting of charged monomers onto PVA have been investigated by varying the initial initiator concentration between 3 and 12 g/l as well as the chain length of the polyvinyl alcohol precursor. The copolymer composition of the copolymers has been obtained from the integrated NMR spectra and potentiometric titration. The main characteristics of the polyelectrolytes are presented in Table 1.

General scheme of grafting charged (meth)acrylate monomer onto poly(vinyl alcohol)



Good agreement between the results for copolymer composition calculated from ^{1}H NMR and potentiometric titration of the chloride counterions has been obtained (Table 1).

Table 1

Code	Molar mass of PVA, g/mol	Charged monomer	Charged monomer grafted, wt%	
			by ^{1}H NMR	by potentiometry
PVA_{10}- $AETMAC_{79}$	10 000	AETMAC	78.83	83.03
PVA_{49}- $AETMAC_{74}$	49 000	AETMAC	73.89	79.45
PVA_{10}- $METMAC_{81}$	10 000	METMAC	81.10	69.60
PVA_{10}- $METMAC_{76}$	10 000	METMAC	75.89	-
PVA_{10}- $METMAC_{58}$	10 000	METMAC	58.13	-
PVA_{49}- $METMAC_{80}$	49 000	METMAC	79.73	75.75
PVA_{49}- $METMAC_{67}$	49 000	METMAC	67.28	-
PVA_{49}- $METMAC_{53}$	49 000	METMAC	52.92	-

METMAC and **AETMAC** stay for the grafted mono-charged monomers [2-(methacryloyloxy)ethyl]-trimethylammonium chloride and [2-(acryloyloxy)ethyl]-trimethylammonium chloride, respectively

The results indicated that the graft copolyelectrolytes only inhibited the growing of strain *S. aureus*, but didn't show effect on the growing of strain *P. aeruginosa*. The minimum inhibitory concentration has been studied. It has been found that at the same grafted amount of the quaternary ammonium groups, the copolymers with longer PVA backbone exhibited lower MIC:

PVA_{10}- $METMAC_{81}$: MIC 0.01%
PVA_{49}- $METMAC_{80}$: MIC 0.001%

Antibacterial effect of the novel graft polymers against gram-negative *P. aeruginosa* (strain PAO1) and gram-positive *S. aureus* (strain MRSA16) was investigated. For the minimal inhibitory concentration (MIC) determination, PVA_{10}-$METMAC_{81}$ copolymer dilution series was created in Mueller Hinton Broth (Oxoid) and diluted PAO1 or MRSA16 overnight culture was added to each well. The plates were shaken overnight. The optical density (OD) was determined spectrophotometrically at 600 nm after overnight incubation. The results are presented in Figure 1 .

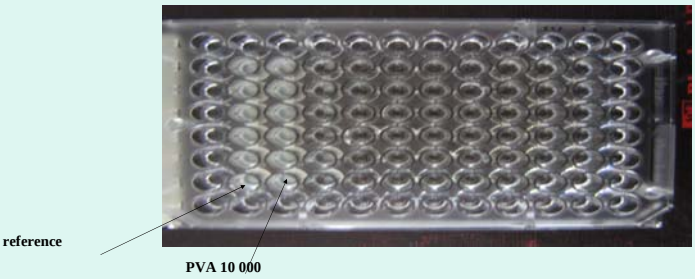
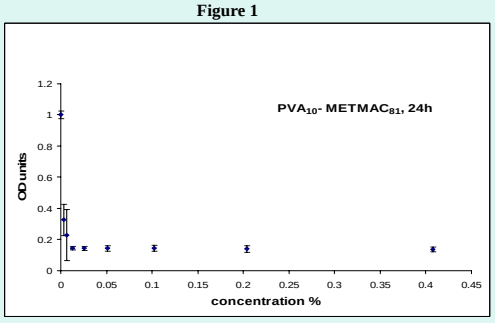


Figure 1



Conclusions

The synthesized copolyelectrolytes based on PVA showed antibacterial activity against gram-positive S. aureus, but didn't show effect on the gram-negative P. aeruginosa. The minimum inhibitory concentration was found to depend on the molar mass of the PVA precursor but not on the copolymer composition.

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2. *Paradossi G., Cavalieri F., Chiessi E., Spagnoli C., Cowman M. K., J. Materials Sci.: Materials in Medcine 14 (2003) 687-691*
3. *Dizman B., Elasri M., Mathias L., Journal of Polymer Science: Part A: Polymer Chemistry, Vol. 44, 5965–5973 (2006)*

Acknowledgments:
S. Todorova acknowledges the Structural Funds and Educational Programs Directorate for financial support (Grant № BG051PO001/07/3.3-02/51 51).

4. 06. 2009
Sofia
IP-BAS

Effect of irradiation dose on surface free energy and thickness of lamellae. DSC and MHV analysis of Ultra-High Molecular Weight Polyethylene

M. Staneva, E. Nedkov,
Institute of Polymers - BAS, 1113 Sofia, Bulgaria

Materials and methods:

Materials investigated:
11 samples γ-irradiated ultra-high molecular weight polyethylene (PE-UHMW);
1 unirradiated sample.

Methods used:
DSC: kinetics of non-isothermal melting according to the modified Nedkov-Atanasov's approach [1];
Vickers microhardness (MHV): new approach to estimating surface free energy [2].

Basic equations:

Kinetics of non-isothermal melting: $\log G_m = \log G_m^0 - \frac{E_d^m}{2.3 \cdot R \cdot T} - \frac{1}{2.3} \cdot \sqrt{\frac{3 \cdot a^2 \cdot M_\eta \cdot \Delta H_F^0}{L_{cr}^m \cdot M_0 \cdot T_m^0 \cdot R \cdot A}} \cdot \sqrt{\frac{\Delta T}{T}}$, $L_{cr}^m = \frac{3 \cdot a^2 \cdot M_\eta \cdot \Delta H_F^0}{5.29 \cdot M_0 \cdot T_m^0 \cdot R \cdot A \cdot (SL_m)^2}$

New approach to estimating surface free energy, using MHV data: $\sigma^{MHV} = a \cdot K \cdot \frac{d_{1\mu m}^2}{d_{real}^{mean}}$

Thompson-Gibbs formula: $\sigma^m = \frac{L_{DSC}^m \cdot \Delta H_F^0 \cdot \Delta T}{2 \cdot T_m^0} \cdot \rho$, $L_{cr}^{MHV} = \frac{2 \cdot \sigma^{MHV} \cdot T_m^0}{\Delta H_F^0 \cdot \Delta T \cdot \rho}$

Radiation effects, causing crystalline structure changes

γ- quantum interacts with the polymer molecule, causing chain-scission. Free radicals are formed. If these radicals are located in the crystalline areas of the polymer, due to "cage effect", recombination is most probable process. The energy released through the recombination is emitted as an exciton into the polymer crystal.
Most probably these excitons move along the polymer chain to the crystalline surface. In this way huge amount of defects are formed on the surface.
The value of the irradiation dose, at which the structure parameter investigated sharply changes its behavior, is denoted as critical dose (CD). In the case of PE-UHMW the CD value is close to 100 kGy.

Radiation annealing (fig. 1 B): Effect observed in the dose range up to CD.
Excitons move along the polymer chain to the lamella surface. The result is chain-scission of the tie molecules and subsequent cross-linking. The amorphous part becomes thinner - the degree of crystallinity increases.

Radiation melting (fig. 1C): Effect observed in the dose range above CD.
The number of excitons formed goes up sharply. The thickness of the amorphous part increases, the thickness of the crystal part decreases, so that the long spacing (quasi-periodicity) remains constant.

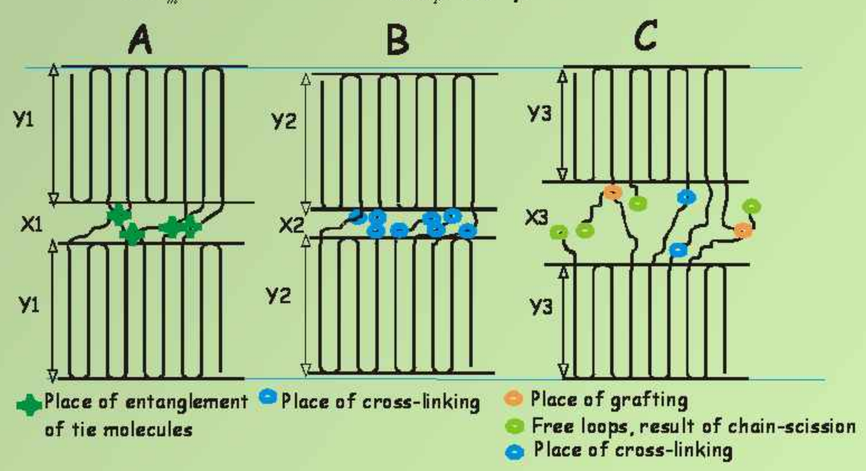

Fig. 1. Changes in polymer structure caused by γ-irradiation: A – lamellar structure of unirradiated sample; B – lamellar structure of irradiated sample during radiation annealing;
C – lamellar structure of irradiated sample during radiation melting.
Y1, Y2, Y3 – thickness of lamellae: Y1 = Y2 > Y3;
X1, X2, X3 – thickness of amorphous region: X1 > X2 < X3

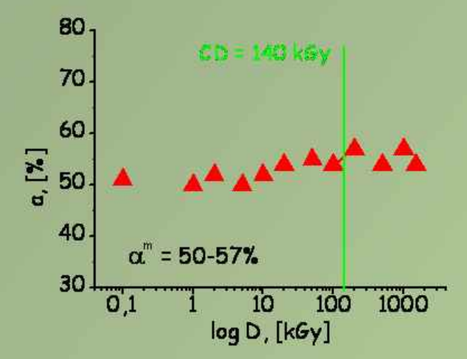

Fig. 5. Effect of the irradiation dose on degree of crystallinity, estimated by DSC

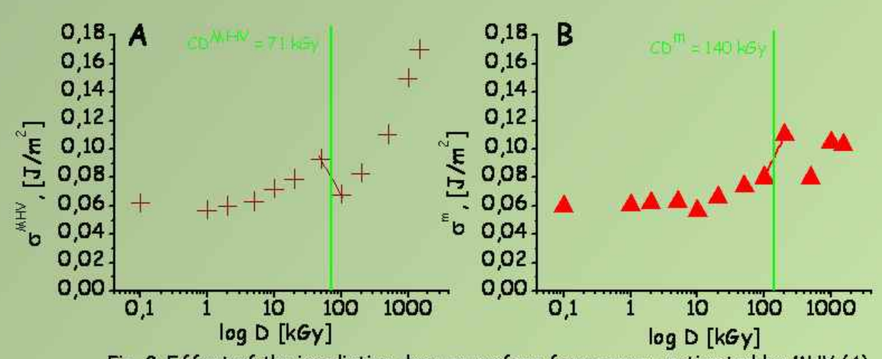

Fig. 2. Effect of the irradiation dose on surface free energy, estimated by MHV (A) and kinetics of non-isothermal melting (B)

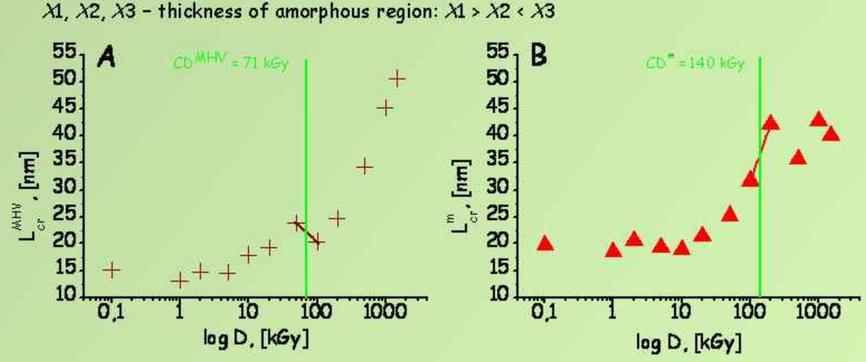

Fig. 3. Effect of the irradiation dose on thickness of lamellae, estimated by MHV (A) and kinetics of non-isothermal melting (B)

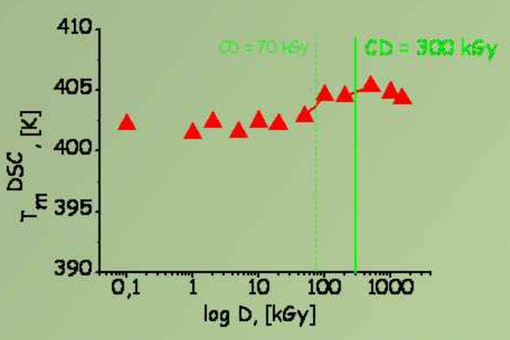

Fig. 6. Effect of the irradiation dose on melting temperature, estimated by DSC

Table 1. Comparison of our results (MHV and DSC studies) with literature data

Irradiated PE-UHMW		Unirradiated PE-UHMW	
Our results, determined by DSC and MHV data ("m" means melting; "MHV" - Vickers microhardness; "cr" - crystal)			
Thickness of lamellae, [nm]	Surface free energy, [J/m²]	Thickness of lamellae, [nm]	Surface free energy, [J/m²]
$L_{cr}^m = 13.9 \div 32.2$	$\sigma^m = 0.057 \div 0.105$	$L_{cr}^m = 14.7$	$\sigma^m = 0.06$
$L_{cr}^{MHV} = 13.1 \div 50.7$	$\sigma^{MHV} = 0.06 \div 0.17$	$L_{cr}^{MHV} = 15.1$	$\sigma^{MHV} = 0.062$
Literature data			
	$\sigma = 0.09$, [4]		$\sigma = 0.06$, [3]
$L_{cr} = 24, D = 25kGy$, [5]			
$L_{cr} = 19, D = 50kGy$; $L_{cr} = 25, D = 100kGy$, [6]		$L_{cr} = 24$, [6]	

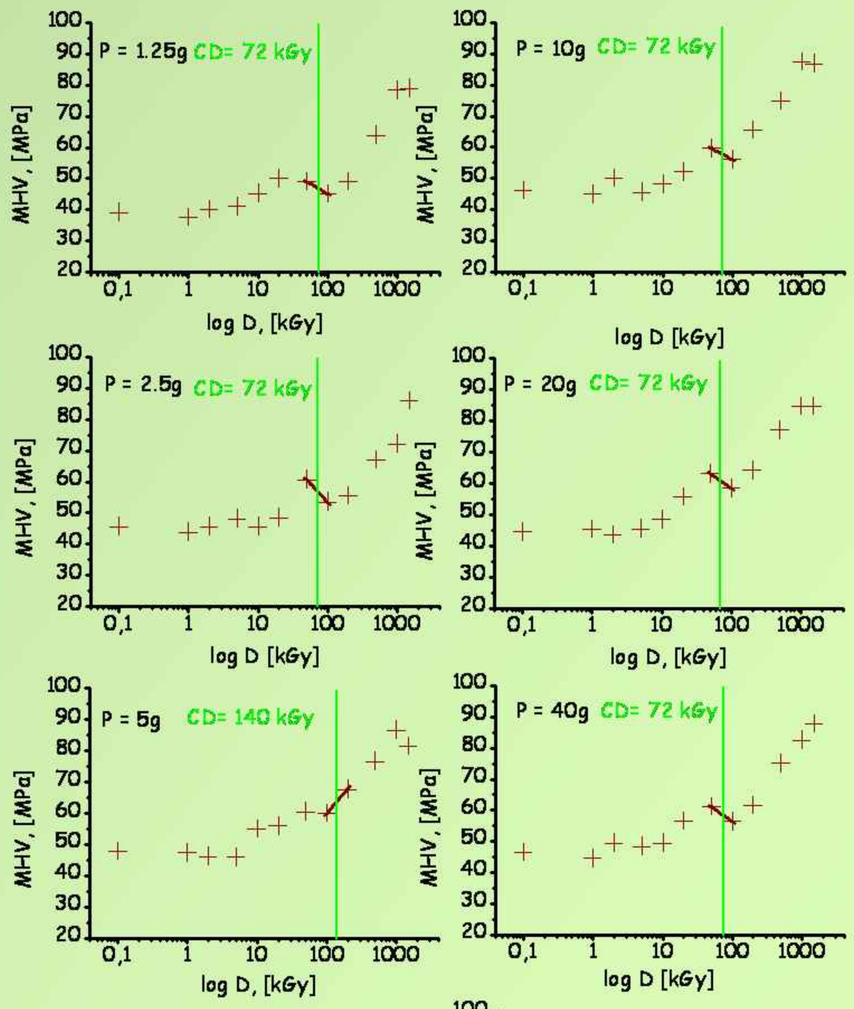

Fig. 4. Effect of the irradiation dose on the Vickers microhardness (MHV).

Conclusions

- The data obtained by our MHV study (Fig. 2A, 3A, 4) shows that MHV, thickness of the lamellae and surface free energy strongly depend on the irradiation dose. All these parameters exponentially increase their values with increasing the irradiation dose.
- The data obtained by our DSC study (Fig. 2B, 3B, 5, 6) shows that the degree of crystallinity, melting temperature , thickness of the lamellae and surface free energy strongly depend on the irradiation dose. All these parameters slowly increase their values with increasing the irradiation dose.
- The values of surface free energy (fig. 2A and 3A), determined by MHV and DSC analysis, are very close to each other.
- The thickness of lamellae (Fig. 2b and 3B), determined by MHV and DSC analysis, are very close to each other.
- The values of surface free energy and thickness of lamellae, determined by MHV and DSC analysis, show good agreement with literature data (Table 1).

References

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